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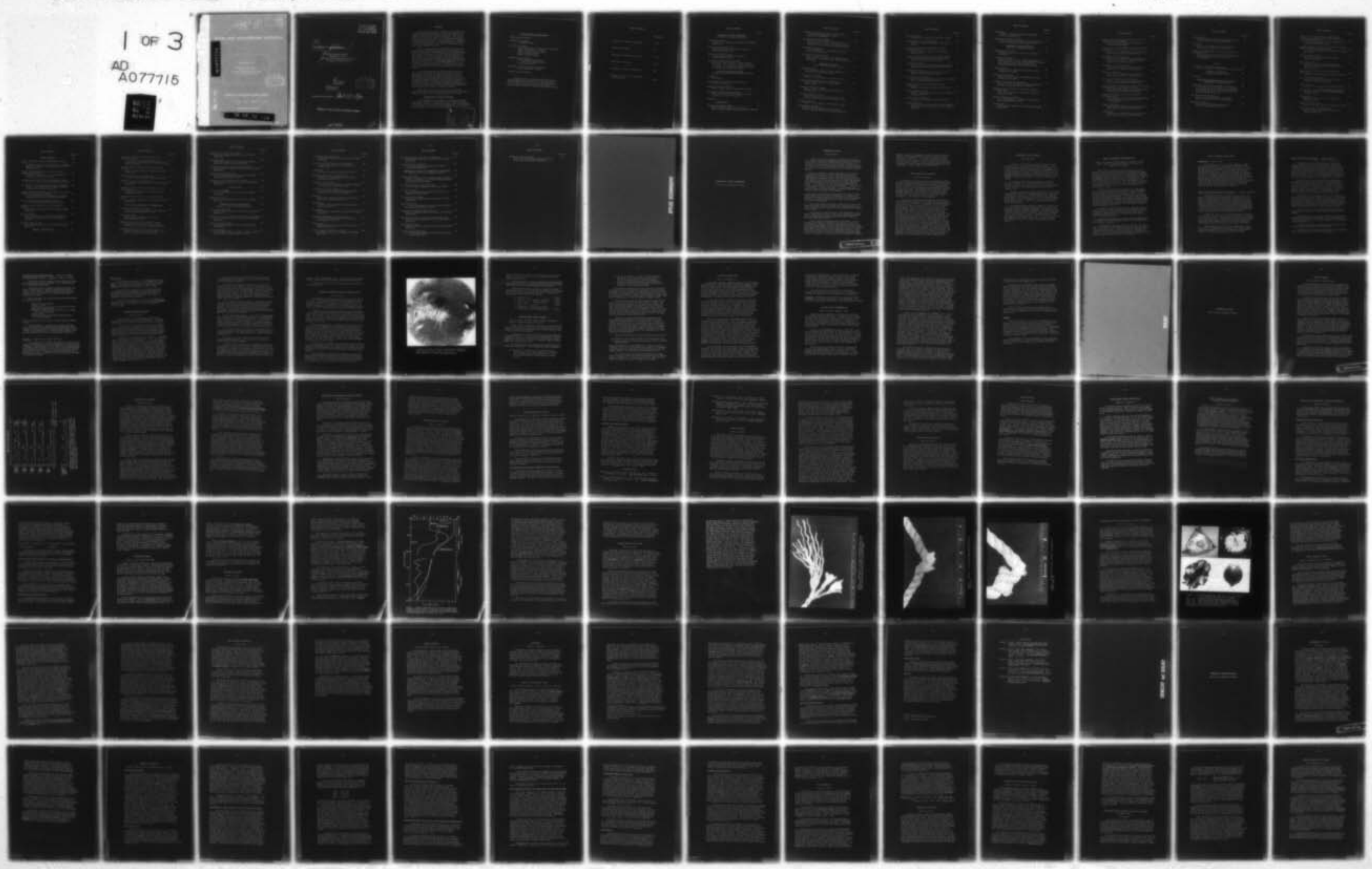

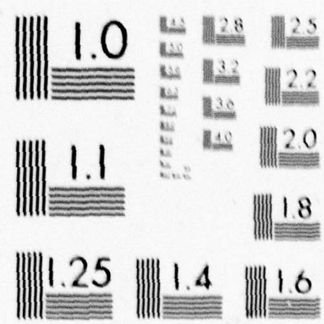

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Reference No. 64-12

SUMMARY OF INVESTIGATIONS
conducted in 1963

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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WHOI — ~~Reference No.~~ 64-12

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SUMMARY OF INVESTIGATIONS CONDUCTED in 1963,

WOODS HOLE OCEANOGRAPHIC INSTITUTION,
Woods Hole, Massachusetts

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April 1964

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APPROVED FOR DISTRIBUTION Paul M. Fye

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Foreword

This collection of brief "summaries of investigations" has been prepared by the members of the research staff of the Woods Hole Oceanographic Institution and this volume represents a return to one of our early traditions. For the first decade or so reports of progress by individual investigators were included as an appendix to each annual report. There were only fourteen such summaries occupying less than seven pages in the 1931 Annual Report; there were but thirteen persons on the research staff at that time.

With the expansion of the Institution during the World War II years it became impractical to include a comprehensive report of progress for each investigator, but the Annual Reports did continue to describe very briefly the work being done by each. With the continued expansion of the Institution the printed annual report has become more and more impersonal and the lack of a comprehensive summary of current investigations has been apparent to all. The Collected Reprints of the Institution have continued, of course, to provide a record of the scientific results obtained by our staff members, but publication delays make these at least a year out of date before they appear.

Last year we prepared the first of this new series of summaries of investigations. These were similar in style to the reports of progress included as appendices to earlier Annual Reports and a limited number of copies were printed. The volume was so enthusiastically received that we have again prepared the summaries for 1963. This collection of summaries is intended not only to supplement the limited information about the scientific investigations included in the Annual Report for 1963, but also to let our friends and associates know what each individual staff member is currently studying.

These summaries have been reviewed by the department chairmen but typed, insofar as possible, without editorial change, adhering strictly to the original manuscript in most cases.

Acknowledgment of Financial Support

A very large part of the support of our research programs came from the agencies and departments of the Federal Government listed below. We wish to express our thanks to these organizations as a whole and to the executives and administrators in them who have been so helpful to us during the past year.

Federal Agencies and Departments

Atomic Energy Commission

Department of Commerce
U.S.Weather Bureau

Department of Defense
Army Signal Research and Development Laboratory
Bureau of Aeronautics, U.S.Navy
Bureau of Naval Weapons, U.S.Navy
Bureau of Ships, U.S.Navy
Office of Naval Research

Department of the Interior
Bureau of Commercial Fisheries,
U.S.Fish and Wildlife Service
U.S.Geological Survey

Department of Health, Education and Welfare
National Institutes of Health

National Science Foundation

The support for our research programs provided by private foundations, individuals and by the Associates of the Woods Hole Institution is also very much appreciated, for it enabled us to initiate projects for research or education which could not be funded through Federal agencies.

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APPLIED OCEANOGRAPHY

DEPARTMENT OF APPLIED OCEANOGRAPHY

Earl E. Hays, Department Chairman

OCEANOGRAPHIC OPTICS

Lincoln Baxter

Study of the effects important in analysis of resolution and contrast in underwater photography and viewing have continued. Collection and review of the widely-scattered literature of research into oceanographic optical conditions, and some theoretical study based on recent developments in optical Fourier analysis have lead to several conclusions which will be tested as soon as possible.

1. In spite of pessimistic reports published by some workers, oceanographic conditions in which properly chosen polarized lighting and/or polarized filtering can significantly improve image quality are probably common. The early pessimism is based on attempts to improve seeing in waters more turbid than average, while measurements of optical conditions by Ivanoff, Waterman, Duntley, etc., suggest to me that the greatest improvement in seeing - obtainable by the use of polarization - will be found in the deepest, clearest ocean waters. In such waters side-scattered light is strongly polarized and forward-scattered light remains polarized for quite large distances.

2. The great concentration of scattering at very small, forward angles suggests that considerable improvement in sharpness and contrast at obtainable resolution would result from proper spacial filtering of the photographic image to match the point spread function of the water path.

3. In cases where one was searching or surveying only for a large object or objects, spacial filtering for the expected image size would permit detection of objects of lower contrast even at extreme optical ranges.

All of these conclusions point to more improvement in clear than in turbid water, but even in clear water significant improvements in visibility and optical range would greatly speed and facilitate many bottom surveys.

In the course of reviewing current publications, I noted that the use of spectral radiance as the principal variable in the equations of radiative transfer (astrophysical practice) lead to a more straightforward derivation than that given in oceanographic papers where it is common to use "monochromatic radiance". Astrophysicists, however, do not use the standard physical terminology and notation for spectral radiance or many other radiometric quantities. For example, in the most recent book on radiative transfer

(Sobolev translated by Gaposchkin, 1963) the concept known to physicists and oceanographers as spectral radiance is called "intensity of radiation". In view of the completeness and excellence of the treatment of radiative transfer in this book, but the confusion created by the non-standard terminology used, I submitted for publication a note comparing astrophysical and oceanographic notation. (WHOI contribution #1450).

DEEP OCEAN ACOUSTIC STRUCTURE

Robert R. Brockhurst

Efforts are continuing to improve our methods of interpreting hydrographic station data for use in under-water acoustic problems. General machine methods are desirable for sorting data by similarity in configuration and for determining limits. As part of this problem, improvements are being made in our new interpolation method. The original form shared with standard Lagrange methods the disadvantage that the resulting curve depended significantly on the choice of independent variable. An improved version provides results that are more nearly invariant when the variables are interchanged.

We are also studying various methods for predicting the results of acoustic experiments in a known velocity structure. It is possible, for example, to approximate the smoothed observed velocity structure in a deep sound channel very closely with a matched set of equations of the form $C = C1 \cosh AZ$ and $C = C2 \, EXP(BZ)$. Since the exact ray path solutions in such layers are well-known, a complete solution can readily be obtained. This was done for a North Atlantic sound channel which had previously been approximated by linear segments. The results proved very surprising. Although the sound velocity of the linear approximation averaged slightly higher than that of the continuous approximation over all depth intervals, the resulting mean horizontal ray velocity was significantly lower for the linear than for the continuous approximation. In addition, the first derivative of mean horizontal ray velocity with axial angle was discontinuous at angles for which the resulting ray reached each profile layer boundary, although both velocity and velocity gradient were continuous across each boundary. The magnitude of this discontinuity does not seem to be related to the change in second derivative across the indicated profile boundary. We are now attempting to explain these results.

TEMPERATURE STRING TELEMETRY

George Erlanger

A system for telemetering sea-water temperatures from a moored buoy to a shore station is being developed. A series of 20 thermistors spaced along a 500'-long cable forming the uppermost link in the buoy's mooring are the temperature sensors. At each thermistor station is also mounted a switching circuit to permit sequential sharing of a common signal lead by all the thermistors. The buoy contains the necessary readout and radio equipment to permit data telemetry to the shore station upon command.

A system of this nature was successfully tested at dockside in January 1963. A further test of a more fully-developed prototype was planned for July 1963, but was prevented due to a failure of the cable manufacturer to deliver the required cable.

The cable in question consists of parallel electrical and strength members housed in a common plastic shroud. This cable is presently on hand, but in the past months a more suitable cable design - with concentric electrical and strength members - has proven feasible for construction. A cable of this second design has been ordered. Both will be tested this winter and in the coming spring.

The original readout equipment comprised an analog, automatically-balanced wheatstone bridge and an analog-to-digital converter along with accessory components. The design of this equipment is presently being simplified in a second design using a digitally-balanced bridge; operation, again, being automatic after a radio command to the buoy. Readout equipment of the first design was used successfully, but it is felt that the later development will be simpler, less costly, and more reliable. This equipment will also be tested at sea during the coming months.

CURRENT MEASUREMENTS FROM MOORED BUOYS

Nicholas P. Fofonoff, Paul B. Stimson, Charles H. Wilkins, John F. Garrett, James Gifford, Myron P. Howland, Jr., and Nellie E. Anderson

During 1963, 35 moored current meter stations were set. Of these 27 were completely recovered, one completely recovered adrift, four partially recovered adrift, two partially recovered on station, and one completely lost. The major effort was applied to EQUALANT I, which accounted for 26 of the above total. Of the remaining stations, two were set at the "Thresher" site, three in Kane Basin in the Arctic, three near Bermuda and one off the continental shelf south of Cape Cod. In addition, nine stations were set in local waters to test modifications of the current meter design.

Several modifications of the design of the instruments and of the mooring system have been made to improve performance but much remains to be done. The transient response of the current meters and their dynamical characteristics in a current are not yet well enough understood. It is evident that motions of the mooring affect the response and introduce spurious velocity signals. Experiments to determine the amplitude of these motions for single moorings and to reduce them by using three-point moorings were carried out off Bermuda. The three-point mooring was severely damaged by "fish bite".

Fish bite is still the primary cause of mooring failure and the quest for a more resistant cable construction continues. In August a buoy was anchored off Bermuda on a nylon cable armored with aluminum wire, but it went adrift after several weeks and remains unreported.

Detection and location of the buoys have been improved by the adoption of a Xenon discharge light and a solid state keyer for the beacon transmitter.

The problems of automatic readout of the data film have been largely overcome by strobing the encoding lights and increasing film transport speed. Computer programs to manipulate and analyse the data are being developed and tested. Programs to decode, list, compute trajectories and develop elementary statistics from the readout magnetic tapes are in operation.

DEEP SEA RESEARCH VEHICLE GROUP

Introduction - Earl E. Hays

The construction of the 6,000 foot submersible ALVIN has been the major concern of this group during 1963. This construction has not proceeded as rapidly as originally planned, but the tempo has increased and at the end of the year is proceeding satisfactorily. In such an undertaking, responsibilities for various phases must be well defined, but contributions to the successful completion of each phase come from the whole group. Working closely with the General Mills Electronics Group (now Applied Science Division of Litton Industries), BuShips and ONR, the Deep Sea Research Vehicle Group has attempted to get the best under-water vehicle we can. We discuss the various aspects of the program below, and also a few other projects in which the group has been involved.

Overall Contract Coordination and Inspection - William O. Rainnie, Jr.

The submersible ALVIN is basically a simple craft, but under the planned operating conditions, nothing can be left to chance. To prosecute this philosophy, we decided to avail ourselves of every opportunity for inspection and quality control. Using the "Special Specifications for a 6,000 foot Submersible" written by BuShips as a guide, our close inspection has paid off, eliminating some potential trouble spots before they became part of the craft. Our inspection (independent of separate materials evaluation) has ranged from monitoring temperatures during heat treats, to machine and acoustic inspection of spheres.

Although the basic craft and its operating specifications were defined in the contract, many details remained to be worked out with the contractor. These included the spatial arrangements inside the sphere, safety features in electrical, hydraulic, and air systems, the obtainment of flexibility in the electrical system and the specific arrangements for outside instruments.

The necessary paper work for the construction of such a craft is great; drawings must be approved, back-of-the-envelope ideas must be made official and most important, communication between all concerned parties must be clear and prompt.

Mechanical Design and Materials - James W. Mavor, Joseph B. Walsh, Henry M. Horn

The design and construction of the pressure hull is the most important part of a deep submersible. The primary responsibility rested with the contractor; our effort was to aid where possible and double check on all proceedings, as far as the actual craft construction. However, this contract with construction of three hulls with intended collapse of one of them in a pressure facility at Southwest Research Institute and testing of the other two, gave us an opportunity to add to the reliability of hull design for deep submersibles in general.

To do this our inspection and material sampling has exceeded normal construction practices. Specimens have been taken from all material used in the hull, before and after all processes (except final welding). These are being tested to carefully determine the properties of the material. The plate, forging inserts, and welds have been magnafluxed, x-rayed and sonically tested as appropriate. A very extensive set of sphericity measurements were taken on the finished hulls.

The purpose of this extensive effort is to determine the cause of failure in the hull we hope to collapse. Such hulls can fail before the ideal yield condition, due to flat spots in supposedly spherical shapes, or due to bending moments created by the necessary thickened areas for windows and hatches. Models are useful for some of this work but full-scale tests allow better strain gage placement and have a higher reliability factor.

The first hull went through preliminary pressure tests in December and the results are being studied in relation to the geometry.

In addition to the hull there are other pressure-resistant components, and problems of mechanical design to be considered. Each drawing is approved by Woods Hole personnel and the pertinent program determined.

A twelfth-scale model of ALVIN was constructed and tested for hydrodynamic and stability characteristics.

A program of stress corrosion experiments were planned with Northeastern University on high strength aluminum.

<u>Instrumentation and Support Equipment</u> - Marvin J. McCamis, William M. Marquet, William C Rainnie,Jr., Henry H. Learnard

The contract called for General Mills to supply the craft and certain basic navigation equipment. Other instrumentation is to be provided by Woods Hole.

Including the basic navigation instruments supplied with ALVIN, we have worked up a navigation package using a gyrocompass, speed indicator, computer, dead reckoning tracer and a doppler sonar. Navigation is also planned using acoustic beacons and reflectors.

Other instruments for which specifications were determined and orders placed were:

- mechanical arm for sampling
- a graphic recorder
- echo sounders for craft depth and height above bottom
- underwater telephone system
- underwater television for more flexibility in viewing than the windows provide
- lights, cameras
- continuous transmission frequency-modulated sonar for distant "vision"

These instruments are being tested to see that they meet specifications.

Charging batteries, replenishing air supplies and maintenance of the craft and instruments are necessary parts of the operation. Three vans have been obtained and are being fitted out to supply this support ability. Within reasonable limits, these vans and equipment should make the operation self-sufficient.

<u>Catamaran</u> - Henry M. Horn, James W. Mavor,Jr.

The availability of two hulls approximately 100 feet long and a beam of 14 feet from the U S.Navy has given us the beginning of a catamaran for handling ALVIN or other submersibles. We have worked up tentative specifications for such a craft, for engineering design and construction bid purposes. We have also constructed a twelfth-scale model to look at sea keeping, and towing properties and to measure stress levels. A catamaran of this size has some advantages for submersible handling.

Other Projects

A one-sixteenth scale model of the ALUMINAUT hull (as of 1962) was strain gaged and collapsed in the Woods Hole pressure chamber. The stress levels and mode of collapse were in good agreement with theoretical predictions. (Mavor, Walsh).

We investigated the feasibility of using a privately-owned submersible (the CETACEAN) to examine Plantagenet Bank off Bermuda but repairs and modifications required were too extensive so we could not meet the desired time schedule. (Rainnie, Learnard, McCamis, Swinhart).

Personnel participated in one cruise of R/V CHAIN on the continental shelf and to Bermuda, in two cruises of the THRESHER search, and part of the Indian Ocean cruise of ATLANTIS II. (Learnard, Hays).

INFORMATION PROCESSING CENTER

Duncan E. Morrill

The activities of the Information Processing Center during 1963 divide roughly into two equal phases - preparing and beginning to use the GE 225 Information Processing System.

In April part of the GE 225 was installed on a temporary basis in the Laboratory of Oceanography: this provided better preparation for the eventual use of the entire system. In June this initial part of the GE 225 was moved to the Laboratory of Marine Sciences; the rest of the system was delivered, and the entire system set up in the new Information Processing Center.

The GE 225 is an intermediate-size computer - the Institution's configuration, a rather large one. It is a very flexible system for a modest cost. Technically, it is a single address binary computer with fixed and floating point binary arithmetic and BCD fixed point arithmetic. It has an 8,096 20-bit word, 18 microsecond core memory, 33 index registers, a real time clock and automatic priority interrupt. Its peripheral units, which are buffered, are 400 card per minute card reader, 100 card per minute card punch, 1000 120-character line per minute printer, four 15000 character per second magnetic tape units, 6 million word disc storage unit, 1000 character per second paper tape reader, 110 character per second paper tape punch, a special communications unit (Datanet 15) for attaching special input and output equipment and 2 Teletype units.

Along with the usual preparatory activities, training, developing general-use programs, et cetera, we continued operation of the Recomp II computer.

By the end of the summer the GE 225 was in general use for the Institution's scientists at about a 6-hour-per-day level; at this writing, in-use time has increased to 10-12 hours per day. The users do most of their own programming. Our principal programming system is Fortran II. The IPC staff, assisted by General Electric Company personnel, and the Computer Department personnel provide training, assistance, consultation, key punching and computer operation. Users may operate the computer for themselves; quite a few like to do this.

This is a sample of the applications: Current Meter Data Reduction, Sediment Size Analysis, Acoustic Ray Tracing, Station Data Reduction, Velocimeter Calibration and Plankton Abundance Analysis. The list of users has grown to about seventy-five. The types of calculations performed include power spectrum, file maintenance, curve fitting, solving partial differential equations, analysis of variance and simulation.

A small, second-hand computer, a G-15, with a special paper tape reader and plotter attached was installed on the ATLANTIS II for the International Indian Ocean Expedition, to provide general-purpose computing. Its heavy use attests to its value, and its reliability was about the same as that for an office installation. A general-purpose computer is a valuable accessory for oceanographic research vessels and it is rapidly becoming an essential one.

The IPC staff consists of a chief, a research associate, a systems programmer, a lead computer operator, a computing assistant, a computer operator, a key punch operator and a systems engineer for the G-15.

The Computer Committee consists of scientists from the various research groups and provides guidance and assistance to the IPC and Institution management.

In process is the attachment of the ADDReSOR, an FM tape-analog-digital converter, to the GE 225. Under consideration for attachment are a graph plotter, cathode ray tube display unit, and a flying spot input unit. The rapidly increasing use of the GE 225 has necessitated consideration of a more powerful replacement for the GE 225. Also under consideration are proposals to augment the staff, to increase its capabilities, broaden its activities and to

provide a limited programming service. Though none have been implemented, several administrative applications are being considered.

Computing has become a valuable and essential tool for the Institution's work.

UNDERWATER PHOTOGRAPHY AND SELF-CONTAINED DIVING

David M. Owen

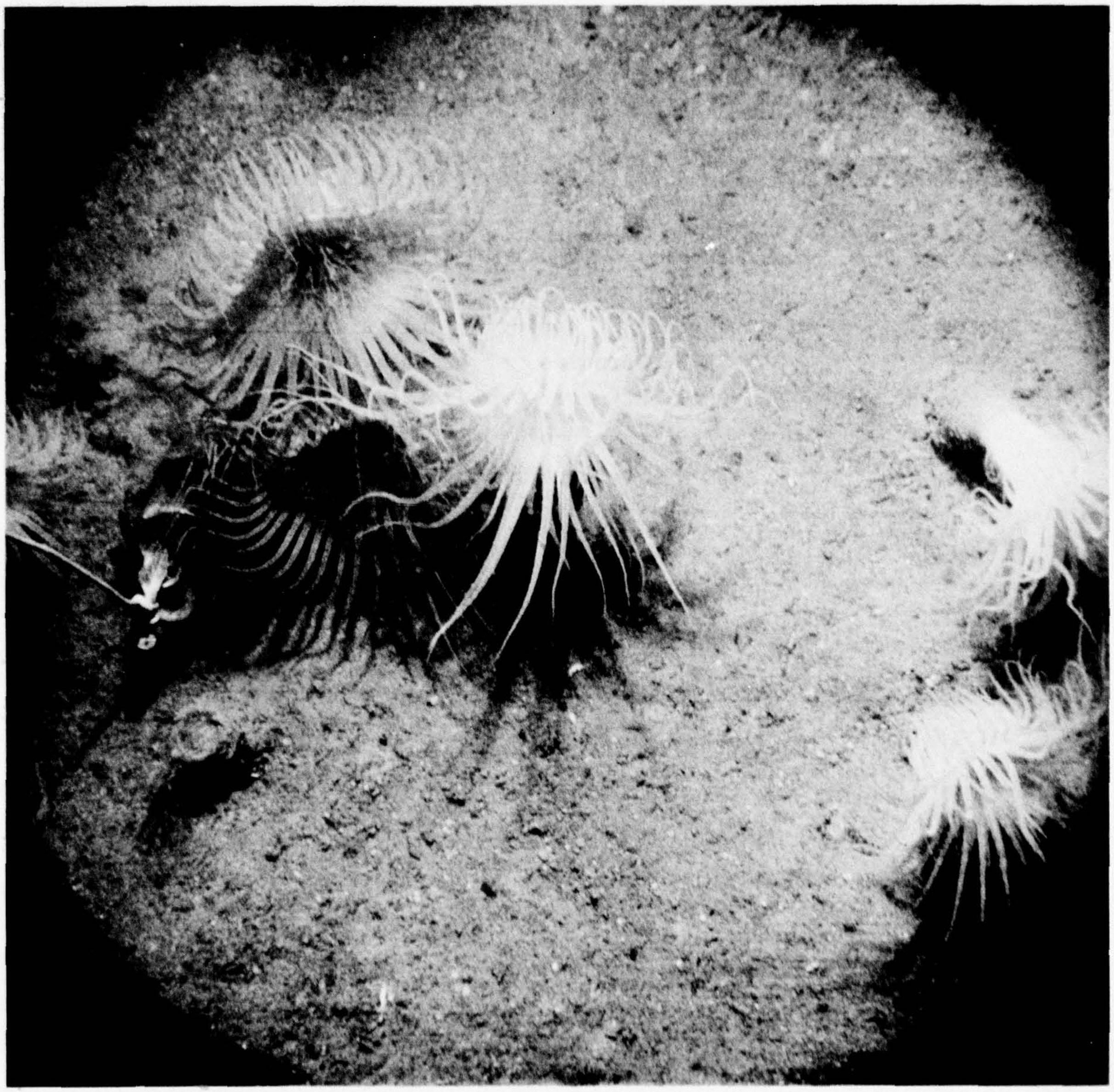
The underwater photography and self-contained diving work in this project is primarily concerned with the development of underwater camera equipment (both deep-sea and hand-held), the use of underwater cameras as a supplementary tool applied to some of the research problems at the Institution, and the development and supervision of the self-contained diving activities at the Institution.

A camera and strobe flash was assembled and attached inside a large Campbell Grab (bottom dredge) for Dr.K.O.Emery of the Institution, who is engaged in the geological study of the Atlantic continental shelf and slope, which is being sponsored by the U.S.Geological Survey. This camera, a 35mm Robot, photographs the undisturbed sediment surface before the Grab closes on approximately the same bottom as shown in the picture.

Bottom photography with a suspended camera during this period took place from R/V ASTERIAS in the Narragansett Bay region (July 10-13). In a continuation of previous work with Lloyd Breslau, the Twin-Robot Stereoscopic Camera was used to photograph small-scale roughness and the various bottom types sampled, and the results will be correlated with the echo-strength and bottom-reflectivity measurements taken by Mr. Breslau. (The camera mentioned takes up to 24 stereoscopic bottom photographs per station, at a lens-to-bottom distance of as little as 28 inches, enabling life-sized enlargements of an area about 14 inches square.)

During Oct.20-28 in Bermuda, accompanied by Dr. Robert Hessler and Mr. George Hampson of W.H.O.I. (N.S.F.), the techniques of diving, hand-held camera photography, and underwater tape recording were used effectively in the direct observation/evaluation of deep-sea dredge operation.

In a continuation of past efforts, additional close-up slow-motion pictures were made during Nov.1-13 of wave-induced sediment movement for Dr. John M. Zeigler of the Institution, on the island of Sint Maarten, N.W.I. The camera set-up for this study has become more sophisticated in that wave height, velocity, time, and a



PHOTOGRAPH OF PEBBLY SAND ATOP A SMALL RIDGE IN THE GULF OF MAINE AT STATION 1052, 42°09.0'N 69°14.0'W, 194 METERS. NOTE BURROWING SEA ANEMONE (Cerianthus borealis).

digital counter (for "tying in" with recordings of these values made on the beach) may be shown in the same picture with the shifting sand particles.

During Nov.19-28, returning to Bermuda and assisting David Rounbehler of the W.H.O.I., underwater motion pictures were taken of the behavior of an anchored Richardson Current Meter.

During 1963 Mr. Owen was personally engaged in various diving projects for a total of 68 days (in addition to overseeing the diving activities of about 26 other W.H.O.I. employees). These projects may be described as follows:

1)	Training dives	42 days
2)	Dredge or coring apparatus evaluation	9 days
3)	Beach studies - sediment movement	9 days
4)	Current meter evaluation	4 days
5)	Maintenance or adjustment of ship or oceanographic tower instrumentation	4 days

MECHANICAL SOUND SOURCE IMP MODEL 2

Arnold G. Sharp, William S. Shultz, Thomas L. Gallerani, Henry P. Leonard, and James R. Sullivan

In May, 1963, Harold Sawyer, the original principal investigator of this contract, passed away after an illness of some three months. Personnel who were members of Mr. Sawyer's group are continuing the work of the contract.

A summary of the work of the contract up to that time was prepared and issued as a technical report, WHOI Reference No.63-21, "Fundamental Studies of the Generation and Transmission of High Amplitude Pressure Pulses in Water", by Harold E. Sawyer, James W. Mavor, Jr., and Arnold G. Sharp.

The present status of the High Intensity Impact Energized Sound Source, IMP Model 2, can be summarized briefly as follows:

(a) The entire "radiating section" (radiating piston, liquid spring system, spring support grid, and outer case) has been completed and assembled, and except for hand finishing of the impact surface, is ready for use.

(b) The "drive section", a system for accelerating the impacting slug or striker to its required velocity, has not yet been built nor completely designed. Efforts are being concentrated on the development of this part of the device and progress has been made as described in the following paragraphs.

Harold Sawyer's proposed device for achieving the required acceleration of the striking mass, a mechanical velocity multiplying linkage, has been studied in detail during the past year and is the subject of the technical report, WHOI Reference No.63-36, "Kinematic and Dynamic Studies of Proposed Drive Linkage for Impact Sound Source, IMP Model 2", by Arnold G. Sharp and Joseph B. Walsh.

The main guide for the striking slug has been machined and honed. This is a cylindrical tube about 5 feet in length. The internal diameter has been held to 14 inches plus or minus .002 inch, and the honing operation has produced a surface finish of about 6 micro-inches R.M.S. A traveling support frame for the guide cylinder has been built in the laboratory. This will be used to bring the guide tube accurately in and out of contact with the radiator section of the IMP during the hand fitting of the impact faces of the slug and the radiating piston.

Because it is recognized that certain engineering difficulties would be encountered in building a device of the type described in Reference No.63-36, it is hoped that a system involving fewer moving parts can be developed. Such a system could take the form of a gas gun in which the discharge from a single cylinder of compressed gas might be applied, directly or through a push rod, to the rear face of the striker. Systems of this type have been successfully demonstrated by two manufacturers of high-energy-rate forging machines.

The main problem areas in the gas gun system are as follows:

(a) High flow, fast response valving of the high-pressure gas.

(b) Effective sealing of the high-pressure gas from the evacuated impact chamber.

Gas gun experiments are being conducted on a small scale in the laboratory so that the above problems may be studied. Concurrently, design calculations are underway for the determination of optimum lengths, diameters, gas pressures, and structural materials.

Initial steps have been taken by representatives of ONR, Boston, to obtain a patent in Harold Sawyer's name for the radiator assembly of IMP Model 2. Similar action is to be taken soon for a patent covering the mechanical "crossbow" drive linkage.

VLF RELATIVE NAVIGATION

Jess H. Stanbrough, Jr.

Long-range navigational experiments using very low frequency transmissions were conducted in 1963; in addition, magnetic measurements were made in the Indian Ocean aboard the R/V ATLANTIS II by Dr. Earl E. Hays and me. Prof.Carl Mennekin, Deputy Scientific Director ONR, London (and of the U.S.Navy Postgraduate School, Monterey, California) joined for one leg of the cruise to assist in the measurements and interpretations. A varian proton precession magnetometer with direct read-out of the earth's field in gammas was employed. The sensor was towed 600 feet behind the ship.

A long-range relative navigational system is obtained with the VLF transmissions when an initial exact position is obtained by other means and all new locations are found relative to this point until another exact position is obtained. With a precision oscillator on board a moving vehicle, changes in the receiving location result in phase differences between the oscillator and the received VLF signals which are indicated as time and computed to a geographical position. Diurnal effects were previously thought to be the limiting factor; recent measurements in the Indian Ocean indicate that these effects may be predictable.

Various carrier-stabilized VLF stations now hold the frequencies of their transmissions to very close limits, a few parts in 10^{11} being typically realized. There are seven VLF stations in the United States and Great Britain that transmit stabilized frequencies. The development of phase tracking receivers for the very low frequencies with very high sensitivities and the availability of simple oscillators with stabilities of a few parts in 10^{11} have made it possible to make phase measurements with small and relatively inexpensive equipment. From November of 1962 to the sailing of ATLANTIS II in July 1963, emphasis was placed on aging the precision oscillator, determining the stability of the VLF stations, and observing the diurnal effects. Automobile trips were made in February about Cape Cod. Short day cruises were made aboard the ASTERIAS in Buzzards Bay and Vineyard Sound in May and June. Positions to within 200 feet were obtained with day path signals.

The VLF equipment was in continuous use on R/V ATLANTIS II throughout the cruise to the Indian Ocean. There were no equipment troubles. Prior to the cruise, Elisabeth Fuglister programmed the GE 225 to give the range and bearing from each one-degree point in the Atlantic and Indian Ocean to seven reference stations. These computations were used to prepare charts. The Navy Oceanographic Office assisted by preparing a special VLF 30 series of charts based

on stations in England, Hawaii, and the Canal Zone. Along with navigational determinations, signal intensities and diurnal patterns were recorded throughout the cruise. VLF records clearly showed the drift of the ship during current and hydrographic station measurements. Generally, the differences between the ship's astronomic positions and the VLF positions varied from three to ten miles; this was without correcting for the drift of the transmitting station.

The desired goal is ± 0.5 miles over long periods. Short period relative positional changes of ± 0.1 miles are now possible and applicable to on-station and drift measurements.

Reference: Stanbrough, J.H. and D.P.Keily, "Long Range Relative Navigation by Very Low Transmissions". Contribution No. 1427, Woods Hole Oceanographic Institution in Deep Sea Research (in press).

ELECTRONICS AND INSTRUMENTATION

Robert G. Walden, Douglas C. Webb

Experiments were conducted to determine the feasibility of torroidally coupling devices such as current meters to single insulated conducting mooring cables, to transmit current data up the cable from a plurality of instruments to a buoy where this data can be stored on magnetic tape and/or be telemetered. A system has been designed, a basic telemetering current meter has been ordered and a field test program is in the planning stages for May, 1964.

In July, the R/V/CRAWFORD was taken to 37°N, 69°W to test certain telemetering gear and some special instruments to facilitate the location of buoys at sea. A current meter 200 ft. below the surface was moored in 4700 meters on July 13, 1963. A special 4-conductor dacron rope was used between the surface buoy and the current meter. Plaited 9/16" nylon rope was used from there to the bottom with about 6% scope. Eight corrosion panels were inserted in the line at 10, 30, 700, 1500, 2200, 3000 and 4100 meters depth.

The current meters data was telemetered on command and received at the ship, Waquoit, Mass., and the International Telephone and Telegraph Station on Long Island, N.Y. It was apparent after 24 hours operation that the Savonius rotor magnetic follower was sticking resulting in abnormally low rotor

counts. The compass and vane continued to perform satisfactorily until July 29 when all binary zeros were missing from the telemetered data. It was possible, because of the data format, to manually reinsert these binary zeros into the data. On August 10 the buoy signal was still strong; however, no bits were being transmitted, only a steady carrier upon interrogation. The buoy continued to respond until October 2, 1963. After this date no signals were heard. On 8 October the CAPT. BILL III was chartered to locate and retrieve the buoy. Heavy weather was encountered in the mooring area and a thorough search failed to locate the buoy. Transmissions from the buoy indicated that it stayed on its mooring (or very close to that geographical position) for 82 days, withstanding an exceptional amount of extremely heavy weather. On October 24, a buoy whose description matched that of this buoy was sighted by U.S.Navy planes at position 21°43'N and 74°06'W or 100 miles north of the eastern tip of Cuba. A message to the Base Commander, Guantanamo Bay, Cuba from ONR, Washington, was sent requesting that subject buoy be picked up. No word has been received yet regarding retrieval.

During this same CRAWFORD trip (CRAWFORD No.95) a test of a telemetering Consolan prototype buoy was conducted. It was determined that it is feasible to retransmit Consolan signals from a buoy, on command, at ranges of 500 miles and to determine the position of the buoy remotely within an accuracy of five miles or better. Subsequent tests indicate useable ranges to 1000 miles. Tests of a radar actuated light and a radar actuated H.F. beacon transmitter were also conducted during this trip. A simple low-power drain radar receiver was used to key the above-mentioned devices upon radar illumination. The light was observed to about 2 miles being limited by the small incandescent bulb used. A new model, using a high-intensity strobe lamp is now completed and will be tested in May. The radar actuated high frequency transmitter could be heard out to 3.5 miles. This test indicated the necessity of increased radar receivers gain on the buoy which has now been accomplished. These two devices would seem to provide the buoy user with two new long-life, low-drain locations aides which would signal their location <u>only</u> when illuminated by the search ship's radar.

On October 30 a Consolan retransmitting buoy was moored five miles east of St. George's, Bermuda, as a surface marker in connection with a mooring test by Stimson. At that time the Nantucket Consolan station was off the air for maintenance purposes; however, the Miami station was received and retransmitted from the buoy. A line of position was received from the buoy which showed agreement with its actual position to within 2 to 3 miles. This

mooring was either carried away or sunk a week later, enabling no further data on the Consolan test.

During the last two months of 1963 plans and equipment have been readied for a test in February 1964 for a wire mooring to a sub-surface float which contains batteries and a telemetering transmitter. The output of this transmitter will feed a surface antenna located on a small float. The purpose of the test is to determine if longer life and greater reliability of the mooring system can be obtained by reducing the effects of surface excitation on the main instruments' float by locating it at depth with a low drag surface unit to support the telemetry antenna. Tests will be run to determine the feasibility of feeding such a surface antenna from a transmitter up to 500 feet below the surface.

During the year specifications were drawn up for an instrument that would disconnect a deep mooring cable from its anchor on acoustic command. We hope to have a prototype instrument in 1964.

ADDReSOR

During the early part of the year the ADDReSOR logic and inter-cabling was modified to enable operation with the GE 225 computer. Prior to actually hooking it onto the computer, several small troubles indicated the advisability of incorporating test circuits into ADDReSOR to simulate the computer. This circuitry was built and upon operation indicated further logic changes which simplified it and apparently added more reliability. A complete test of the ADDReSOR logic is now possible without the necessity of computer time.

The racks have also been rearranged to improve appearance and ease of operation. The basic clock has been redesigned and built to provide variable sampling rates between 10 ms. and 10 seconds.

BIOLOGY

DEPARTMENT OF BIOLOGY

John H. Ryther, Department Chairman

NUTRIENT CHEMISTRY

David A. McGill, Nathaniel Corwin

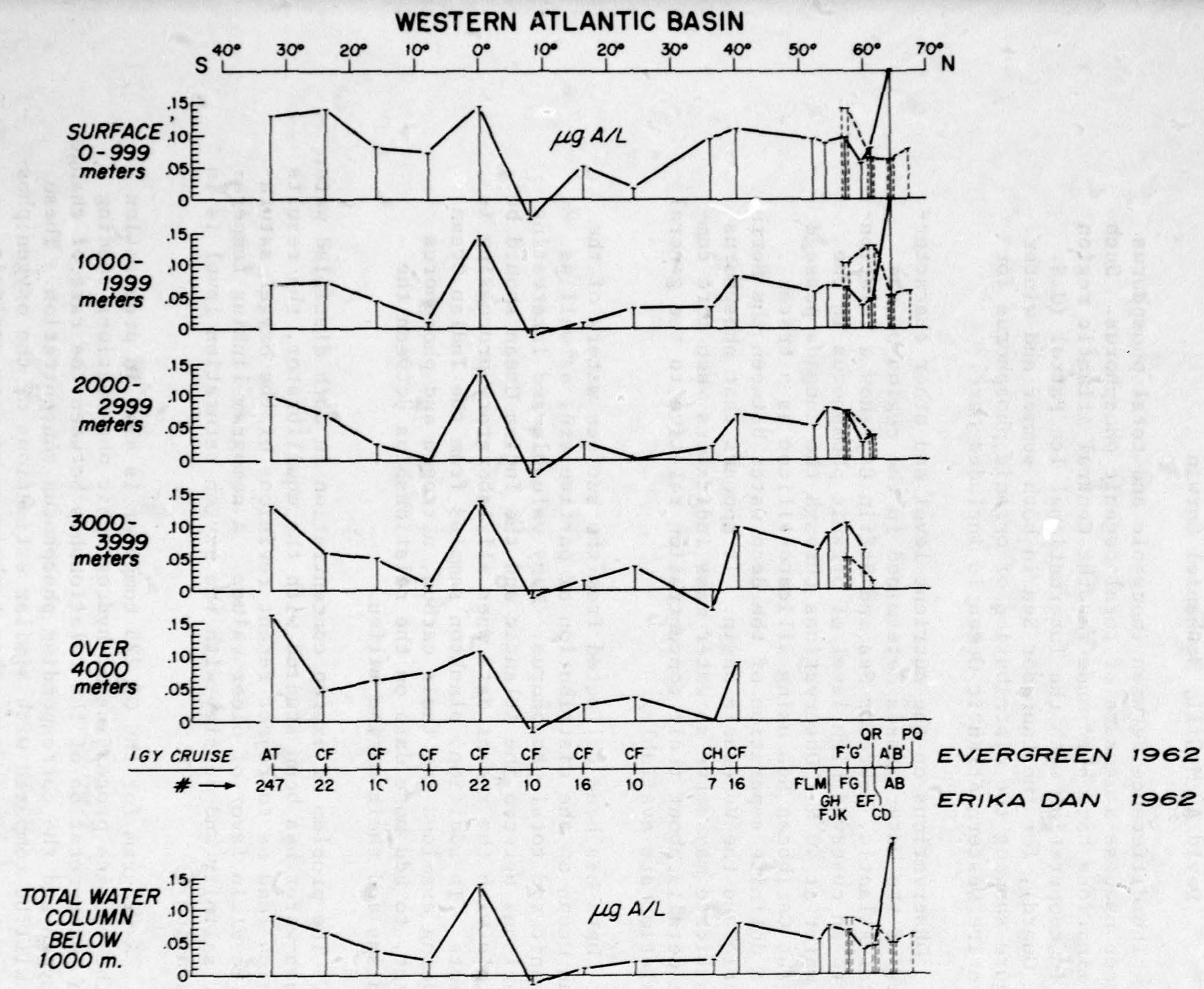
The difference between inorganic and total phosphorus has been used as a measure of total organic phosphorus. Such determinations have been made for the Central Atlantic region and, in cooperation with the International Ice Patrol (U.S. Coast Guard), for the Labrador Sea in both summer and winter. A figure showing the distribution of organic phosphorus for the entire western Atlantic Ocean is included here.

Observations on the nutrient level and other characteristics of the water masses determined in the region of the Central Atlantic, Labrador Sea and Baffin Bay show a relationship to an observed high level of organic phosphorus in the deep water at 40°N. Observations through the Anegada passage into the Caribbean Sea using silicate-silicon as a tracer show a definite separation of the deep water between the North Atlantic and the Venezuela basin. It appears that phosphorus and silicate may serve as water mass indicators when more complete details about their concentration relative to the general circulation are available.

Data has been collected from the surface waters of the Indian Ocean on the distribution of particulate, as well as inorganic and total phosphorus. Many valuable and interesting comparisons between the Atlantic and the Indian Ocean should be possible with the recent data when all laboratory processing is complete. In addition, plankton samples from the Indian Ocean are being examined for their carbon, nitrogen and phosphorus content, to add more data on the relationships between the organisms and their marine milieu.

The problem of oxygen concentration in both distilled water and sea water has been studied with the equilibrator, the results of which lead us to reject recent revisions of the oxygen saturation level in favor of older values. A nomogram linking temperature, salinity and density with the oxygen saturation level is in preparation.

A program for the GE 225 computer is also in preparation for the routine processing of hydrographic observations leading to an interpretation of the relationship between the rate of change in oxygen and the corresponding phosphorus concentration. These data will be compared with similar estimations of the oxygen:phosphorus ratio derived from other techniques of data analysis.



DISTRIBUTION OF ORGANIC PHOSPHORUS (μgA/L) FOR THE WESTERN ATLANTIC BASIN, TREATED AS A FREQUENCY DISTRIBUTION FOR 1000-m DEPTH INTERVALS THROUGHOUT THE WATER COLUMN. EVERGREEN 1962 DATA ARE FOR SUMMER, WHILE ERIKA DAN 1962 ARE WINTER OBSERVATIONS FOR THE LABRADOR SEA.

DISTRIBUTION OF NITROGEN

Ralph F. Vaccaro

Accelerated oceanographic observations within recent years, especially in some remote and previously little-known areas, will require a reexamination of many concepts in marine ecology in terms of newer information. Among these are impressive quantities of new data arising from such efforts as the International Geophysical Year, several Antarctic expeditions and most recently the International Indian Ocean Program. In addition, simultaneous observations within the Atlantic and Pacific Oceans have also been accelerated. Many of these programs have placed common emphasis on the distribution and availability of plant nutrients in the oceans insofar as an unceasing and balanced exchange of nutrient elements between resident marine organisms and their environment is essential for all life in the sea. With respect to nitrogen, nitrate comprises some sixty per cent of the available nitrogen, hence it presumably plays a dominant role in marine protein synthesis.

Nitrate like other soluble constituents of sea water is transported by advection and is exchanged between adjacent water masses by eddy diffusion. However, since nitrate-nitrogen also becomes incorporated into the life cycle it is further dispersed by the migratory and gravitational movements of marine organisms and their residues. Distinction between these modes of transport is not always easy but basically depends upon isolation of the amount of oxygen depletion associated with the contributing biological phenomena. In general, there is a consistent relationship between the spacial distribution of nitrate and the amount of oxygen depletion at and below intermediate depths which suggests a high degree of uniformity with respect to the controlling processes.

Iselin (1939) traced conservative properties which identify discrete water masses through the North Atlantic thermocline to their ultimate origin at or near the surface at successively higher latitudes. On this basis, the intermediate water layer (σ_t = 27.0 - 27.5) in the equatorial region which centers around a depth of 800 m and extends northward to about 15°, is contiguous with the subantarctic area of surface convergence located between 42° and 50°S. When surface-oriented at the higher latitudes, these waters reflect their close association with the atmosphere by becoming virtually oxygen-saturated and, following periods of surface cooling, can acquire sufficient density to cause their departure from the surface by sinking. After convergence,

this relatively fresh but cold, dense water is transported horizontally toward the equator by isentropic movement along surfaces of equal potential density. Nutrient residuals associated with oxygen saturation at the time of surface occupancy have been designated preformed nitrate and phosphate by Redfield (1934) and like salinity can be expected to behave conservatively following descent below the photic layer.

Throughout the Indian and within the southern and central regions of the Atlantic and Pacific Oceans, nitrate concentrations below 2000 m are also largely regulated by nitrate preformed in Antarctic regions. The characteristic salinity and temperature of these waters are closely duplicated in the Antarctic circumpolar sea and at even more southerly locations off Antarctica itself. Initially rich in nitrate, these waters undergo little attenuation as far north as the equator following their convergence and departure from high latitudes.

In the southernmost Antarctic Ocean preformed nitrate is uniformly distributed down to 1500 m at a concentration near 20 microgram atoms per liter. At the above depth, the water temperature is about -0.30°C and the salinity 34.65 parts per thousand. Such measurements closely approximate conditions observed below 4000 m in the proximal basins of the neighboring oceans. This hydrographic continuity appears to mean that much of the nitrate at these great depths is transported by horizontal advection. However, the available data also indicate variable and significant departures in total nitrate from the 20 microgram atoms-per-liter level especially in the Indian Ocean. Presumably this is due to the more confined nature and sluggish circulation in the Indian Ocean as opposed to the Atlantic.

This subject will be investigated further during the coming year following the anticipated completion of a longitudinal section in the Indian Ocean extending from the equator as far south as the subtropical convergence at about 40°S. Although a scarcity of deep nitrate observations from the Pacific will remain, we anticipate completion of a comprehensive revaluation of the role of inorganic nitrogen in the sea sometime during the coming year.

DISTRIBUTION AND REGENERATION OF ORGANIC MATTER

David W. Menzel

The obvious sparcity of information concerning the distribution of dissolved and solid organic matter in sea water is based largely on the fact that existing methods are time-consuming and subject to large error. During the past year a new method was developed for the measurement of dissolved organic carbon in sea water which has increased the rapidity of determinations from 6 to over 100 samples per day at an accuracy of two times better than previous methods. In addition, a companion method was developed for the determination of particulate carbon with an accuracy of $\pm$ 10 μg C or 3 to 4 times better than earlier techniques.

The purpose of developing these techniques was two-fold: (1) to enable a practical mapping of the world's oceans in order to study decomposition rates, biological turnover and the relation of carbon to the seasonal cycles of primary production in the open sea; and (2) to provide tools for the measurement of respiration, excretion and carbon synthesis by phytoplankton in culture.

Measurements of particulate forms of carbon have been made on 1963 cruises of the ATLANTIS II and CHAIN in the Northwestern Atlantic and on two cruises of the ANTON BRUUN in the Indian Ocean. Basically, these data show values which range from 30 μg C/l. in poorly productive surface and deep waters in both oceans to over 200 μg C in highly productive areas. No direct correlation can be shown between chlorophyll, here assumed to be an index of living plant matter, and levels of carbon. The reason for this is that 0-100% of the carbon may be present as detritus, or "non-living" carbon, and the relative proportions of living:dead matter may vary considerably over the oceans as a whole and within a water column at any one station. We are attempting now to develop methods for the direct estimation of detrital carbon.

Measurements of dissolved organic carbon have also been made in the North Atlantic and Indian Oceans and have demonstrated a rather unpredictable distribution. One common and expected feature is relatively higher values in the surface decreasing to the permanent thermocline, and then fluctuating some within the water column. Fluctuations in deep water presumably are correlated with the presence of water masses of different age and origin, and dissolved carbon content may therefore be useful as a tracer of water movement.

Preliminary work with cultures has been carried out to determine normal changes in carbon : nitrogen : phosphorus : chlorophyll ratios that may be developed by plants under varying

conditions of light and nutrients. Measurements of carbon synthesis have been made by analytical and C-14 techniques and good correlation has been demonstrated between these two methods. Considerable argument has occurred in the literature regarding the reliability of the C-14 technique used to measure plant growth in extended experiments. Our results indicate agreement between indicated (C-14) and measured carbon synthesis to within 10% over 24 hours. C-14 measurements are consistently lower; about 8% of this difference can be accounted for by respiratory losses and only 2% by excretory losses of the labeled carbon.

EXCRETORY PRODUCTS OF PLANKTON

Edward J. Kuenzler

A study of rates of excretion of several physiologically important elements by marine zooplankton has been almost completed. Radioactive isotopes of iodine, zinc, iron, cobalt, and manganese were measured in the tissues and excreta of pteropods, pyrasomas, copepods, euphausiids, and other animals contaminated by fall-out from a nuclear-weapon test. Whereas a large part of the iodine and zinc were excreted as soluble anions and cations, iron and manganese appeared mostly in particulate form. Whether this difference resulted from defecation of indigestible particles containing radio-iron and radio-manganese or from immediate precipitation from soluble forms of these elements after excretion from the animal is not known. Excretory rates were variable but often totalled about one per cent per hour. The data on excretory rates combined with knowledge of population densities of diurnally-migrating species obtained from quantitative hauls in the same area show that zooplankton can be important in transporting elements through the thermocline.

As part of a long-range study of the dissolved organic phosphorus compounds in sea water, we studied the alkaline phosphatase of marine algae. This enzyme was found in representatives of most of the important types of planktonic algae. Very low levels of phosphate completely repressed production of the enzyme, but, when phosphorus deficiency inhibited cell growth and cell division, enzyme production began and continued at a linear rate for many days. The pH optimum for enzyme activity was 8 to 10 for most species studied. The enzyme seemed to be on or near the cell surface, but a very small amount was often found in solution in the culture medium. When phosphate esters such as glucose-6-phosphate, adenosine monophosphate, or alpha-glycerophosphate were added to cultures of phosphorus-deficient algae, they assimilated phosphorus at the same rate regardless of substrate. Furthermore, when C^{14}-

labeled glucose-6-phosphate was added to cultures of deficient algae, the C^{14} remained in solution while the phosphorus was assimilated. It is apparent, therefore, that many species of algae may be capable of hydrolyzing certain organic phosphorus compounds extracellularly rather than assimilating the whole molecule in order to alleviate their phosphorus deficiency.

PARTICULATE MATTER IN THE SEA

William H. Sutcliffe, Jr., Edward R. B.ylor and William S. Maddux

This summary of our 1963 work (currently supported by N.S.F.) presents three theories and preliminary observations consistent with them. If confirmed, these three theories would expalin, at least in part, the small-scale patchiness of plankton, the origin of particulate matter in the ocean described by Nishizawa and Riley (1962), and would solve the missing-food paradox of copepods enunciated by Marshall and Orr (1955). Although apparently unconnected, these three theories are closely linked by the hydrodynamic variables of Langmuir circulation and the colloidal phenomena of adsorption, desorption and peptization.

The first of the three theories relates zoo- and phytoplankton patchiness to hydrodynamic patchiness by means of: (a) hunting and feeding behavior of zooplankton that respond to the hydrodynamic variables of Langmuir circulation, and (b) adsorption of phytoplankton to foam that is subsequently concentrated by the flow patterns of Langmuir circulation.

The second theory accounts for the origin of particulate organic matter in the ocean by adsorption of dissolved material onto surfaces that are compressed and peptized to particles by the forces of Langmuir circulation.

The third theory proposes that the particulate organic matter formed by Langmuir circulation is suitable for filter feeders and hence may be the missing food in the missing-food paradox of copepods.

Distribution of Surface-Water Temperatures and Zooplankton

Our theory relating to Langmuir circulation to plankton abundance predicts that measurements made during a cross-wind tow will show that small, sharp horizontal gradients of temperature are correlated with small, sharp horizontal gradients of plankton abundance. Currently the tests of this prediction are

made by pushing ahead of the boat a fast-response thermister and the transducer of the Maddux-Kanwisher plankton counter. The output of these instruments is recorded on magnetic tape for subsequent statistical analyses by an electronic computer.

We have collected approximately fifteen rolls of magnetic tape data describing the surface-water temperature and plankton abundance in the Sargasso Sea. The computer analysis of these data will be done in 1964. A preliminary analysis has been made using a desk calculator to check the performance of the electronic computer and we have examined 6,000 pairs of temperature readings with their corresponding plankton-abundance measurements. The results of this preliminary analysis are consistent with our theory that zooplankters tend to collect in windrows.

Production of organic particles

Bubbles rising through sea water adsorb organic materials and collect phytoplankton cells. When these bubbles reach the sea surface they burst, releasing the adhering phytoplankton. According to our theory of the origin of organic particles, the adsorbed compounds on bubbles form monomolecular films which are carried by convergent flow to the windrows where compression, collapse, and peptization of these films return the organic matter to the water column in the form of particles. Some bubbles may be held beneath the surface in the trajectories suggested by Stommel (1949). These bubbles of gas may grow larger and escape to burst at the surface, grow smaller until only the adsorbed material of the bubble skin remains as an organic particle, or be ingested, skin and all, by a filter feeder. These processes account, in part, for the greatly increased light scattering observable beneath the windrows, and may also explain the increased phosphate concentrations we have found in these zones (Subcliffe *et al*, 1963).

Laboratory experiments (Baylor *et al*, 1962; Sutcliffe *et al*, 1963) confirm that dissolved organic material in filtered sea water adsorbs to bubbles, forms films and is converted to particles, and is proved to have nutritive value by having supported the growth of cultures of *Artemia* (Baylor and Sutcliffe, 1963).

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LIGHT IN THE SEA

George L. Clarke

Observations on the transparency of the sea and the occurrence of bioluminescence, made in the slope water southeast of New York, were compared with similar studies carried out in the Brownson Deep and around the Virgin Islands. The changes in light conditions were scrutinized in relation to the vertical migrations of deep scattering layers as obtained by Dr.R.H.Backus, using the Precision Graphic Recorder. Highly transparent water was observed at stations in both areas. The sensitivity of the photometer and the clarity of the water were so great that daylight could be detected to 1090 meters, a depth greater than ever before reported. The attenuation coefficient for the stratum from 400 meters to 700 meters in the Brownson Deep was k = .023 and thus represents the clearest water ever reported (except for a few observations at depths less than 100 meters).

Luminescent flashing was detected at every station and at every depth where light from the surface did not interfere. The frequency, duration, and intensity of the flashes varied greatly with depth, revealing the presence of luminescent organisms of different species, or at least with very different behavior patterns, in the different strata.

One or two deep scattering layers were detected below 300 meters during the middle of the day. These layers tended to split toward the beginning of their rapid upward migration with the result that three or four separate layers could be detected

during the sunset period. The same, or similar, layers formed before sunrise in the upper layers and descended rapidly during the early morning hours. In the Brownson Deep the animals of certain of the scattering layers swam upward for a vertical distance of over 100 meters, at a rate greater than 12 meters per minute. This high rate, the fastest upward migration ever reported, indicates that the animals involved were fishes or fast-moving invertebrates such as shrimp or squid.

By using the deep-sea photometer in the inverted position and placing over the window a view restrictor limiting the cone of light received to 19^{o}, it was possible to record the flashes of luminescence at the depths and times at which the principal scattering layers were migrating rapidly. Before this procedure was developed, such observation had been prevented by the interference of the ambient light. In this way evidence was obtained that a higher rate of flashing occurred during periods of active vertical migration. Since luminescence has been shown to be so prevalent in the upper 1500 meters of the open sea and to vary according to depth and to the activity of the organism present, it is evident that this phenomenon is important in the lives of the inhabitants. To what extent and under what conditions luminescent flashing plays a critical part in obtaining food, in avoiding enemies, or in attracting others of the same species must be determined by further investigation.

Participation in the International Indian Ocean Expedition was arranged to obtain badly needed information on light conditions in that ocean and to compare the findings with the results of our extensive observations in the Atlantic. A total of 19 lowerings of the photometer were carried out aboard the R/V ANTON BRUUN between Bombay and Mauritius. Transparency was determined and records of luminescent flashing were obtained. A new procedure was established in which the hydrographic measurements were made at the same time as the light studies. This was accomplished by attaching the Nansen bottles to the conducting cable used for the photometer, and attaching the depth meter with its mercury switch to the deepest of the reversing water bottles. This plan not only saved a great deal of time, but it also provided: (1) a record of the moment when the messenger tripped the deepest water bottle, (2) a precise measure of the depth, and (3) a determination of the transparency which was immediately available for productivity studies and for any other ship-board investigations. From Mauritius south to latitude $43^{o}S$ and returning to Aden my program of light studies was continued by Mr. Mahlon G. Kelly. More than 20 additional series lowerings were carried out for transparency measurements and records of bioluminescence. During

these cruises laboratory studies of luminescent flashing were conducted on a variety of planktonic invertebrates obtained by net hauls.

From the latitude of Bombay southward transparency was found to be only moderately high, but near the equator it was as high as in other tropical regions. South of the equator extreme clarity was detected at all depths. At one station the transparency was higher from 200 meters to 700 meters than ever previously recorded for these depths, or at any depth, except for a few measurements of strata less than 25 meters thick near the surface.

Throughout the investigation there was evidence of a relation between the amount of luminescence and the volume of animals caught in the net hauls. The light records and the net catches are now being analyzed to relate the type of luminescent flashing with the kinds of animals present.

PHYTOPLANKTON DISTRIBUTION

Edward M. Hulburt

During 1963 phytoplankton samples were collected from the southern Sargasso Sea (Bermuda to the West Indies) in January and August. The enumeration of the species from these samples has been finished. These counts, in conjunction with similar counts from the northern Sargasso Sea (Bermuda to the Gulf Stream off Woods Hole) throughout the year, show a seasonal change in the flora. In winter and spring a majority of species are more abundant either toward the north or more abundant to the south, while a minority of species are more or less uniformly distributed. In summer all species tend toward uniformity of distribution. In winter and spring the water column is homogeneous to 200-300 meters in the north but is stratified in the south, while in summer it is similarly stratified throughout the Sargasso Sea. The changes in the flora correlate very well with these hydrographic changes.

ALGAL PHYSIOLOGY

Johan Hellebust

Studies on algal excretion which were initiated in 1962 were continued. Rates of excretion of photoassimilated carbon were determined for 22 species of marine unicellular algae in culture during periods of log-phase growth, and for natural marine phytoplankton populations from Vineyard Sound and the Gulf of Maine. Some information about the composition of the excreted material was obtained using C^{14} tracer techniques.

Most of the algae excreted 3-6% of their photoassimilated carbon during logarithmic growth. Moderate changes in light intensity did not cause significant changes in excretion rates in most cases. However, very high light intensities (10-12,000ft. candles) increased the rates of excretion considerably, possibly through damage to the cells by photooxidation. Several species, *Olisthodiscus* sp., *Chaetoceros pelagicus*, *Chlorococcum* sp. and *Skeletonéma costatum* excreted measurable amounts of glycolic acid. A manuscript on these studies is under preparation for publication.

Preliminary investigations on protein synthesis in algal chromatophores were begun last summer in cooperation with Mr. David Habeshaw (WHOI summer fellow). Chromatophores were isolated by an aqueous method from *Rhizosolenia setigera*. The incorporation of C^{14}-labeled leucine into the protein of the chromatophores was determined under various experimental conditions. Very low incorporation rates were obtained due to 1) low yield of isolated chromatophores, and 2) inactivation or loss of enzymes necessary for protein synthesis. Studies on protein synthesis in algal chromatophores will be continued with more suitable algae and improved isolation techniques.

Work is now in progress to determine what enzymatic step(s) are limiting to the rate of photosynthesis during diurnal fluctuations in photosynthesis by synchronized cultures of algae.

PHYTOPLANKTON CULTURE AND NUTRITION

Robert R. L. Guillard

We continued study of vitamin B_{12} specificity of marine diatoms, extending both the number of species and the number of B_{12} analogues considered. The diversity of responses shown by the different species can be applied to bioassay of natural water.

Several additional species of diatoms and flagellates were cultured in enriched sea water, but not all of the cultures were maintained. We are interested in the survival of single cells isolated into vessels of culture medium or sea water. Almost all individuals of some species survive, while few to none do of other species. Observations suggest that apparently minor details of the procedures used to prepare media may be responsible for some of the failures to survive. This must be understood better before we proceed to compare the physiological responses, under controlled environmental conditions, of clones freshly isolated from nature.

We continued morphological studies, chiefly of diatoms. <u>Navicula</u> <u>ostrearia</u>, which is known for the production of a water-soluble blue pigment external to the chromatophores, has been cultured. We also isolated diatom clones that are structurally identical to the blue ones (by light and electron microscopy), but which have not produced the blue pigment under any culture conditions to which we have subjected them.

Continued attempts were made to control the production of gametes by diatoms in culture through manipulation of environmental conditions. While we observed both gametes and auxospores, the numbers were small and the occurrence could not be controlled or predicted.

For the first time we successfully shipped cold-water algae by airmail, using vacuum bottles and plastic insulated containers. One hundred and forty-five sub-cultures of various algae were supplied to workers at institutions away from Woods Hole.

ECOLOGY, PHYSIOLOGY AND BIOCHEMISTRY OF MARINE NITRIFYING BACTERIA

Stanley W. Watson

We are continuing studies on bacterial nitrification in the ocean. In 1962 we isolated and described a new nitrifying bacterium Nitrosocystis oceanus. During 1963 most of our time was spent studying the metabolic pathway by which this nitrifying bacterium oxidizes ammonia to nitrite. Since six electrons are transferred during this oxidation it was speculated that three distinct steps were involved in this reaction. Evidence obtained however in this laboratory during this last year suggests that four rather than three steps are involved. We are presently separating and purifying the enzymes involved in this reaction sequence. Although much work is still required, considerable progress has been made on this problem.

In our ecological studies we made enrichment cultures for nitrifying bacteria from the Indian and Atlantic Oceans. From the Indian Ocean nitrifying bacteria which oxidized ammonia to nitrite were cultured. Active nitrification was detected in these original enrichment cultures in 13-16 days while in previous cultures from the Atlantic, nitrification was not detected until 30-60 days following the enrichment of sea water with ammonia. This observation indicates that nitrification occurs more rapidly in the Indian Ocean than in the Atlantic Ocean.

From inshore Atlantic waters we succeeded in culturing for the first time marine nitrifying bacteria which oxidized nitrite to nitrate. It is now being attempted to isolate in pure culture both of the above types of bacteria for future ecological and biochemical studies.

PHYSIOLOGY AND BIOCHEMISTRY OF MARINE PHYTOPLANKTON

Charles S. Yentsch

The principal efforts this year have been concerned with (1) the relationship of certain hydrographic features and plant production, (2) chlorophyll decomposition in the natural environment, (3) light absorption and phytoplankton, (4) diurnal cycles of chloroplyll synthesis, photosynthesis chloroplyll and bioluminescence.

Geostrophy and Plant Production

Three cruises in areas of intensive water-mass movement have demonstrated a positive relationship between water-mass velocity (computed from the slope of the density field) and the amount of chlorophyll. High chlorophyll concentrations occur to the left of the main body of the current in the northern hemisphere, to the right in the southern and are associated with the higher density water nearer the surface in these regions.

A mathematical model has been designed to predict chlorophyll concentrations in the section of currents. The model considers that high density nutrient rich water is "tilted" into the euphotic zone by geostrophic action and that chlorophyll synthesis depends only upon nutrients and light. The model demonstrated that, (a) chlorophyll concentration depends on the slope of the density field and hence the velocity of the current, (b) the growth of a population of plants is from the base of the euphotic zone upwards, and (c) chlorophyll concentration increases from right to left across the current cross section in the northern hemisphere and vice versa in the southern. Model predictions are in good agreement with direct observations.

Chlorophyll Decomposition

As a consequence of the development of a highly sensitive and precise method for measuring chlorophyll and its magnesium void decomposition product phaeophytin, these measurements can be made in open ocean waters. As a part of the ATLANTIS II Indian Ocean Survey 2000 observations of chlorophyll and phaeophytin have been made throughout the Indian Ocean. The total quantities of the pigments vary widely; however, a general feature is one of increasing phaeophytin with water depth.

The decomposition of chlorophyll <u>a</u> in cultures of marine plankton algae has been studied. Phaeophytin is not produced in cultures which are nitrogen and phosphorus deficient. Phaeophytin

is produced after 100 hours in darkness. Microscopic examinations of these cultures has shown that the appearance of phaeophytin is accompanied by considerable cell disintegration. This pigmented cell debris accumulates as large particles and possesses an orange-reddish fluorescence when radiated with blue light. In contrast, intact cells exhibit a dark red fluorescence. Surprisingly, cultures kept in darkness for more than two months regain their capacity for growth in a matter of days when placed in light, the phaeophytin being replaced by chlorophyll a. The general scheme of decomposition of chlorophyll in nature is described by the equation below:

$$\text{chlorophyll}\,\underline{a} + \text{esterase} \xrightarrow{-\text{phytol}} \text{chlorophyllide}\,\underline{a} + \text{enzyme(?)} \xrightarrow{-M_6H} \text{phaeophorbide}\,\underline{a}$$

or

phaeophytin

Data indicates that disassociation of phytol from chlorophyll must occur almost simultaneously with the formation of phaeophytin or phaeophorbide and that chlorophyllide is not a long-standing product of cells kept in darkness.

Diurnal Cycles of Phytosynthesis: Chlorophyll and Bioluminescence

Further inquiry into the causative factors of diurnal fluctuations of photosynthetic capacity and chlorophyll content has led to an examination of the rates of these processes in marine cultures held under a variety of light conditions.

Compared to continuous illumination, a dark period of the order of hours is sufficient to augment photosynthesis considerably and markedly affects pigment synthesis. Photosynthetic rate and chlorophyll content are also related to stage of cell division in cultures. The possibility that natural populations are synchronized with respect to division rate is being studied as well as photosynthetic rate, respiration, and chlorophyll content during cell division.

With R.H.Backus the causative factors in diurnal cycles of bioluminescence are being investigated. Maximum bioluminescence occurs after darkness and decreases rapidly after sunrise. The cycle appears to be a function of light inhibition similar to the pattern observed in cultures of certain dinoflagellates.

Light absorption and phytoplankton

The major particulate substance absorbing light in coastal waters is an ultra-violet absorber, the action of which extends into the visible region. The attenuation of blue-green light is caused

primarily by this material while absorption of red light is caused by chlorophyll absorption. Observations in the open ocean show much less of the U.V. absorbing material and in these cases the soret bands of the phytoplankton pigments are clearly visible.

By subtraction of the attenuation by chloroplastic pigments of phytoplankton the spectral characteristics of the U.V. absorbing material may be determined. The material is characterized by slow increase in attenuation from long to short wavelengths in the visible spectrum termination in a broad absorption peak at 265 μ .. A second and much stronger band is found at 210 μ . The nature of the material is not known but is certainly derived from plants. The material is considered to be largely a residue of the carrier protein and degradation products of the chloroplastic pigments.

ZOOPLANKTON TAXONOMY

George D. Grice and Kuni Hulsemann

Studies continued in 1963 on the systematics, distribution and abundance of bathypelagic copepods. Major emphasis was devoted to a series of plankton samples collected by the National Institute of Oceanography, Surrey, England. These samples were obtained to depths of 5000 meters by means of a Nansen vertical net in the eastern North Atlantic between 30° and 60°N and constitute one of the most important deep sea plankton collections yet made.

We have recently completed identifying, measuring and counting the species and individuals in these samples. Illustrations have been prepared for 30 new species and at least three new genera. Approximately 15 species have been redescribed. In all more than 160 species of calanoid copepods have been found in the samples. Analyses of the data are currently being made on the variation in species diversity, size and abundance with depth. Preliminary impressions are 1) maximum diversity occurs well below the surface, 2) there is a dramatic decrease in numerical abundance at great depths and 3) very small copepod species predominate in the deeper samples.

Many unique distribution records have been recorded in the North Atlantic samples. The genus <u>Tanyrhinus</u> erected in 1936 on the basis of a single specimen collected north of the Great Barrier Reef, Australia and not since reported was found in two of our

samples. The distinctive species Mimocalanus inflatus described without illustrations in 1949 from a single specimen collected off the coast of Washington and not subsequently reported appeared in one of our deep samples. Specimens of Scolecithricella lamellifer and Scaphocalanus bogorovi originally described from the coast of Japan and the Kuril-Kamchatka trench respectively, have been detected in our samples as well as two species of Racovitzanus not hitherto known from the North Atlantic.

Papers on Foxtonia babatula n. gen. et n. sp., a species typical of waters deeper than 2000 meters in the eastern North Atlantic (30°-40°N), and on the occurrence of species found between 41°N and 15°N in the western North Atlantic have appeared. A manuscript describing a new siphonostome copepod genus has been submitted for publication. The new siphonostome is of interest because most known species are small (less than 2.0 mm) and occur on shallow-water hosts. The present species measured 5.2 mm and was found in samples collected between 3000 and 5000 meters. No obvious hosts were present.

During the year over 500 cataloged entries have been made in the WHOI collections. Most of the entries are copepods, the collections now consisting of representatives of 106 genera and approximately 340 species.

ZOOPLANKTON PHYSIOLOGY

Robert J. Conover

Studies on the large arctic copepod Calanus hyperboreus have been continued. A superficially normal adult male, which molted from a stage V copepodid in the laboratory, proved to have a number of feminine characteristics as well. Although it had the male five-jointed urosome, it was too large for a male, had the general body contours of the female, and it fed readily unlike normal males. Comparison of the mouthparts with normal males and females revealed a predominance of feminine characters. The genital system showed both male and female structures.

Differentiation of primary and secondary sexual characteristics in this species takes place late in the last intermolt prior to the adult stage. No reliable means of sexing the animals was found before the gonads had begun to take on adult characteristics shortly before the molt. Molting to the adult stage in nature was

largely restricted to the breeding season, late fall and winter. Immature animals could be kept in the laboratory for many months, but the period of molting and development still coincided quite well with that in nature. Stage V brought into the laboratory during the breeding season produced nearly equal numbers of males and females, but stage V captured at other seasons produced females exclusively.

The suggestion is made that some factor in the natural environment influences the sexual differentiation in this copepod, resulting in the production of sufficient males for successful reproduction only when they are needed.

Physiological studies on *Calanus hyperboreus* were mainly concerned with feeding and utilization of food. Growth studies have revealed efficiencies of 18 to 39%. *Calanus hyperboreus* Stage V, when fed diatoms *Thalassiosira fluviatilis* or *Rhizosolenia setigera*, both having caloric contents of around 5200-5300 calories/gram, put on nearly all their new weight in fat having a caloric content over 10,100 calories/gram. This is accomplished although less than 60% of the total organic matter in the food organism is assimilated. Either assimilation is selective for high-energy compounds, which are less abundant in actively growing algae, or else algal proteins and carbohydrate are converted to copepod fat through loss of ammonia and oxidized carbon. During 85 days' starvation, the weight loss in this animal was only about 20%, attributable almost entirely to fat metabolism.

Investigations of the nutritive value of various cultures of algae are still quite preliminary but certain organisms definitely appear to be assimilated better than others. The green algae *Dunaliella*, though more than 95% organic matter and soft-bodied, is poorly assimilated as is the common neritic diatom, *Skeletonema costatum*. On the other hand a large *Coscinodiscus* (300-400μ) is readily eaten and assimilated although its test constitutes 60-70% of its dry weight.

In conjunction with assimilation studies, preliminary bacterial analyses of fecal pellets were made with the kind cooperation of R.F.Vaccaro. Numbers range from 400 to 4000 cells/fecal pellet, amounting to roughly 10^{11} to 10^{12} bacteria/gram of dry pellets. Among the numerous types present were chitin utilizers and agar liquifiers.

Short cruises to the Gulf of Maine were made in January, May, June, September and December. A longer April cruise to study the spring bloom, was cancelled due to the sinking of the THRESHER.

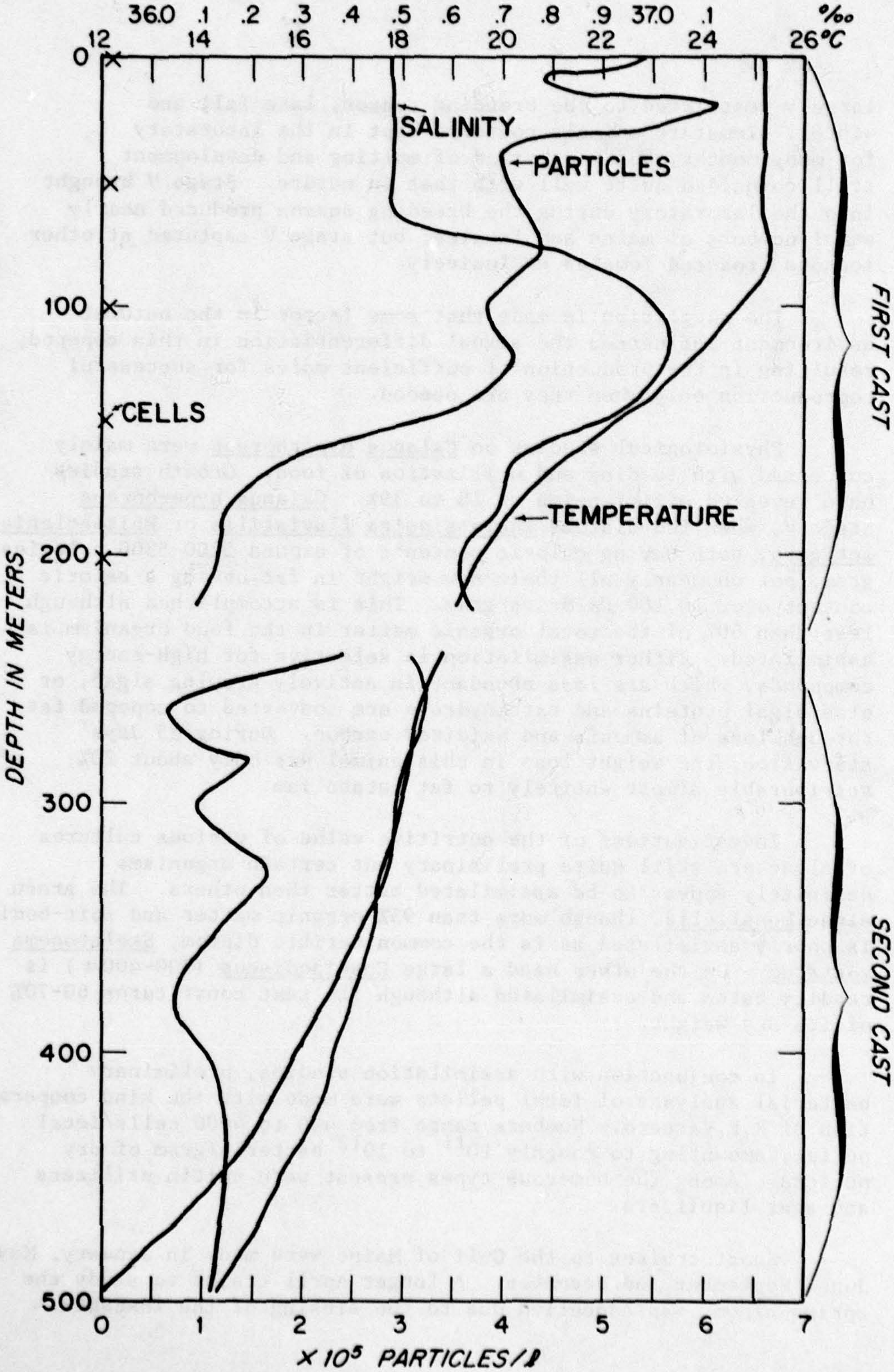

FIGURE 1. VERTICAL DISTRIBUTION IN RELATION TO TEMPERATURE, SALINITY AND CELL COUNTS OF PARTICLES WITH APPROXIMATE MEAN DIAMETER GREATER THAN 4μ AS DETECTED BY THE COULTER COUNTER[R]. R/V CHAIN STATION #570, 21°48'N, 64°57.5'W.

The parachute drogue technique was employed to maintain contact with specific water masses during diurnal studies. None of the stations showed great enough diurnal fluctuations in particulate carbon and chlorophyll for the calculation of productivity or grazing. Additional cruises have shown that the total quantity of particulate carbon beneath a square meter of sea surface varies by not more than 36% from season to season (23.3 g/m^2 in January, 36.5 g/m^2 in late April) but the vertical distribution varies markedly. During low productivity periods total carbon in the lower half of the water column may exceed that above while during the spring and summer the reverse is true. On the other hand, chlorophyll ranged from 31 mg/m^2 in January to 324 mg/m^2 in late April. Zooplankton biomass increased from 2.6 g dry wt/m^2 in March to 7.9 g in May. Maximum biomass is probably obtained in summer with 11.7 g being observed in June 1963 and 10.6 in August 1962. Contribution of the microzooplankton was determined for only one cruise in May and amounted to 1.3 g dry wt/m^2 compared with 7.3 for the larger plankton. In the same size range as the microzooplankton, one phytoplankton organism, Ceratium tripos, contributed 2.1 g dry wt/m^2. As fragments of Ceratium have been observed in fecal pellets of Gulf of Maine Calanus, this large cell may prove rather important as a food for the copepods of the area.

Considerable time has been spent on evaluation of the Coulter Counter® as a research tool in oceanography. The instrument will enumerate accurately laboratory cultures of unicellular organisms of similar size. It can also be used to distinguish between different-sized organisms in mixed culture. However it cannot distinguish living and dead particles and thus counts detritus as well as living cells. Particle counts of natural waters, even Sargasso Sea, are always several orders of magnitude greater than optical cell counts (see Figure). However, the role of detritus is becoming increasingly important to the study of production biology. In surface waters, Coulter counts usually correlate well with total chlorophyll or particulate carbon.

Total particles are most numerous in the surface waters but their distribution does not follow a smooth curve with depth. In the surface layers high and low particle counts may alternate at adjacent depths without any obvious correlation with other physical or biological parameters (Figure). In the Sargasso Sea minimum particle counts generally occur at mid-depths but even there were found 50-100 particles/ml with mean diameter greater than 4 μ .

The Coulter Counter measures the resistance of a particle suspended in an electrolyte as it passes through an electric field.

Theoretically the resistance is proportional to the volume of the particle. This relation holds true for particles with maximum and minimum linear dimensions varying not more than 2 or 3 times, but when one dimension is many times the other two, it is doubtful that a direct proportionality is maintained. However, the counter may be used to compute rough "total particle volume" for any sample. A maximum value of 6.852 $mm^3/l.$ was recorded off No Mans Land at the south of Vineyard Sound and a minimum of 0.014 at 1400 meters at 22°40'N, 65°00'W in the Sargasso Sea.

MARINE FOULING IN DEEP WATER

Harry J. Turner

Preliminary observations on various anchored buoys set between Woods Hole and Bermuda have shown that significant fouling appears to be limited to the upper 500 meters. As a general pattern, objects within 20 to 30 meters of the surface accumulate stalked barnacles of the genus Lepas with an occasional specimen of the genus Chonchoderma. Hydroids of the Campanularia type accumulate on moored objects down to a depth of 500 meters, and separate moorings usually contain different species. There appears to be little significant fouling below 500 meters although pelagic Coelenterates, usually Siphonophores, often become tangled with the mooring lines at all depths.

Samples of deep-water fouling in the Tongue of the Ocean supplied by the Atlantic Underwater Testing Experimental Center have been examined. In this locality fouling is abundant, probably because of the tropical climate and proximity to land masses. In the upper 50 meters the fouling community resembles a benthic community that might be expected on the bottom in shallow water. Assorted species of filimentous algae grow luxuriently forming a mat containing errant polychaetes, crabs and shrimp. Imbedded in the mat are various tropical oysters, mussels (Pinna) and scallops. There are also numerous stalked barnacles. At greater depths fouling consists of Campanularia-type hydroids down to 250 meters and an unidentified species of Tubularia-type hydroid from that level to 500 meters. Apparently, objects moored in deep water in the Tongue of the Ocean provide biological niches in a vertical column on which a surface at any given depth acquires a benthic community similar to that which might be found at an equivalent depth on the bottom nearer shore.

Our attempts at making additional determinations of open ocean fouling with our own apparatus have been unsuccessful because

we have been unable to maintain deep-water moorings for periods long enough to permit significant growth of organisms. Three moorings in 2,000 meters southeast of Bermuda have been lost in spite of the fact that the specifications of the ropes and hardware included a large factor of safety. We suspect that failures are due to some organism biting the lines because failed moorings previously set by others have shown evidence of this. Additional confirmation of the "fish bite" cause of failures was obtained recently. A group from the Department of Applied Oceanography set a buoy moored by three separate lines in deep water off Bermuda. Within a few days one of the lines parted at a depth of 800 meters. Upon retrieval, it was found that two of the strands of the three-strand 9/16 polypropylene rope had been cut off sharply and the third appeared to have parted due to stress failure. Figure 1 is a photograph of the broken end of the rope. An additional near-failure was found in which one strand had been cut (Figure 2) and a second strand partially cut (Figure 3). Examination of the fibers with the microscope showed that the severed fibers had apparently been cut with a very sharp object while those of the frayed strand had broken under tension. We have now obtained some experimental nylon rope imbedded in a flexible plastic and intend to moor another buoy with this material. We hope that the organism that is cutting the lines may be assisted by the fibrous nature of the conventional ropes and that a smooth outer surface may act as a deterrent.

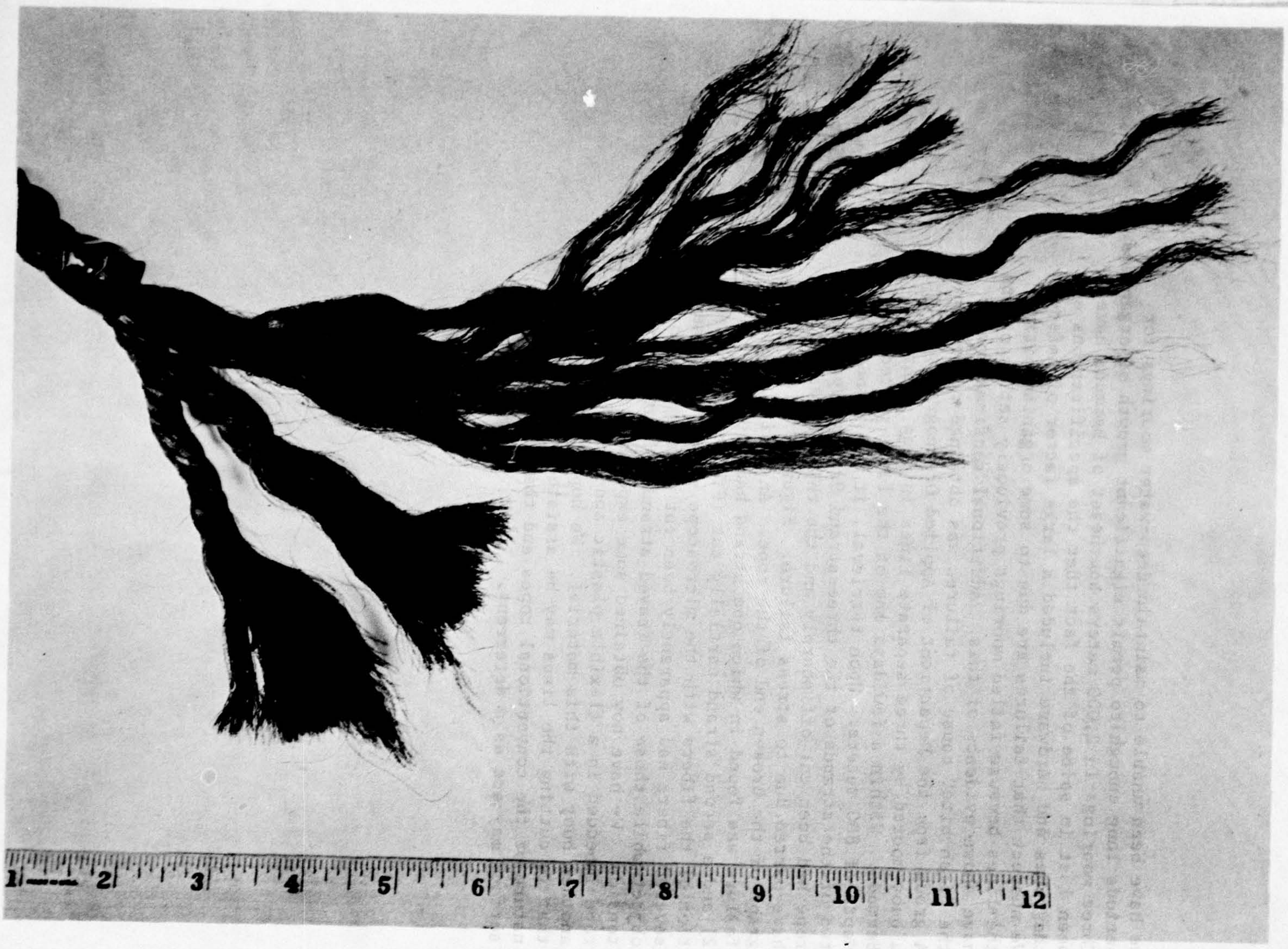

FIGURE 1. BROKEN END OF A 9/16-INCH POLYPROPYLENE MOORING ROPE THAT FAILED AT A DEPTH OF 800 METERS. TWO STRANDS ARE CUT OFF SHARPLY AND THE THIRD FRAYED OUT AS FROM STRESS FAILURE.

FIGURE 2. PORTION OF A 9/16-INCH POLYPROPYLENE ROPE WITH ONE STRAND CUT.

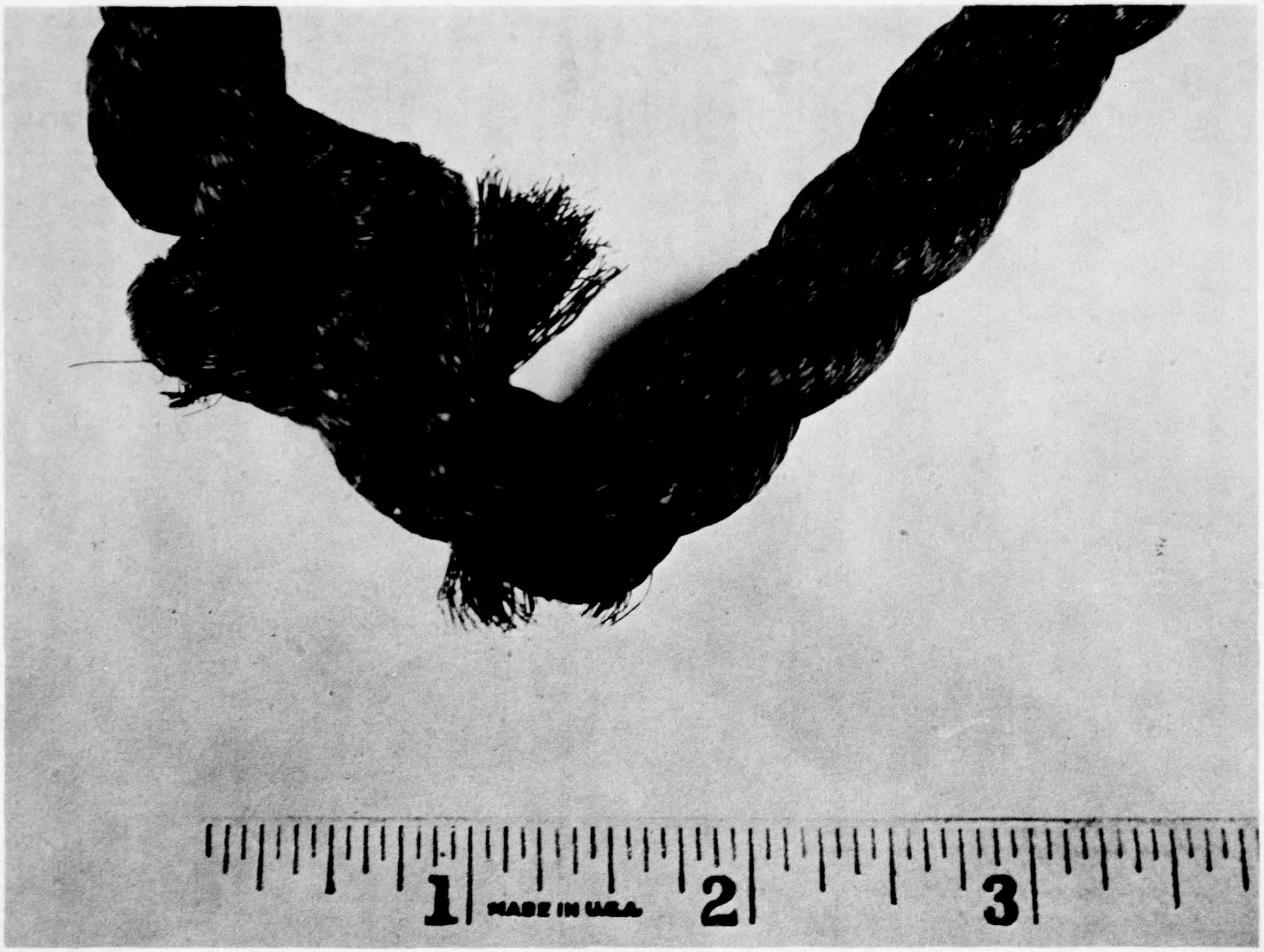

FIGURE 3. REVERSE VIEW OF FIGURE 2 SHOWING A FEW FIBERS OF A SECOND STRAND CUT.

REPRODUCTION AND LARVAL DEVELOPMENT OF MARINE INVERTEBRATES

Rudolf S. Scheltema

Invertebrate larvae taken from plankton samples in the open sea fall into three general categories: (1) those belonging to organisms which spend their adult life afloat, (2) those originating from organisms attached to pelagic seaweed of the genus Sargassum, and (3) those which come from organisms on the bottom. It has been the latter two categories with which I have been concerned.

Among the commonest larval forms are those of the Sargassum organisms: a cyphonautes presumed to be that of Membranipora tuberculata, the veliger of the Sargassum snail, Litiopa melanostoma, and the zoea and megalops believed to be that of Portunus sayi.

The forms which originate from the bottom constitute a wide variety and include tornaria, auricularia, trochophores, veligers of gastropods and lamellibranchs, and the larvae of sipunculids, brachiopods, polychaetes and stomatopods. The origin of the benthonic larvae must be either from the continental shelf or from the deeper waters of the slope or abyss. Until a larva is related to its adult, the species cannot be determined and consequently the place of its origin cannot be inferred.

Of particular interest has been the distribution of certain sipunculid larvae (See Fig. 1, lower right). These have been found in plankton samples between 30° and 40° north latitude from the edge of the Gulf Stream to the Azores. They occur more than a thousand miles from the nearest coast. It is of great interest to know whether these larvae originate from the abyss or whether they are carried over great distances, in this instance perhaps across the Atlantic in an easterly direction and hence southwesterly into the Sargasso Sea. The principal obstacle for planktotrophic development of larvae from abyssal species is the necessity to move several thousands of meters vertically to the surface of the sea to feed. The large distances which larvae may be transported is of great zoogeographic importance.

During the past two years deep-sea dredge samples have been collected in order to investigate reproduction of the deep-sea benthos. Fourteen samples from a station 2000 meters deep, located near the bottom of the continental slope at approximately 39°42' north latitude, 70°39' west longitude, have been collected.

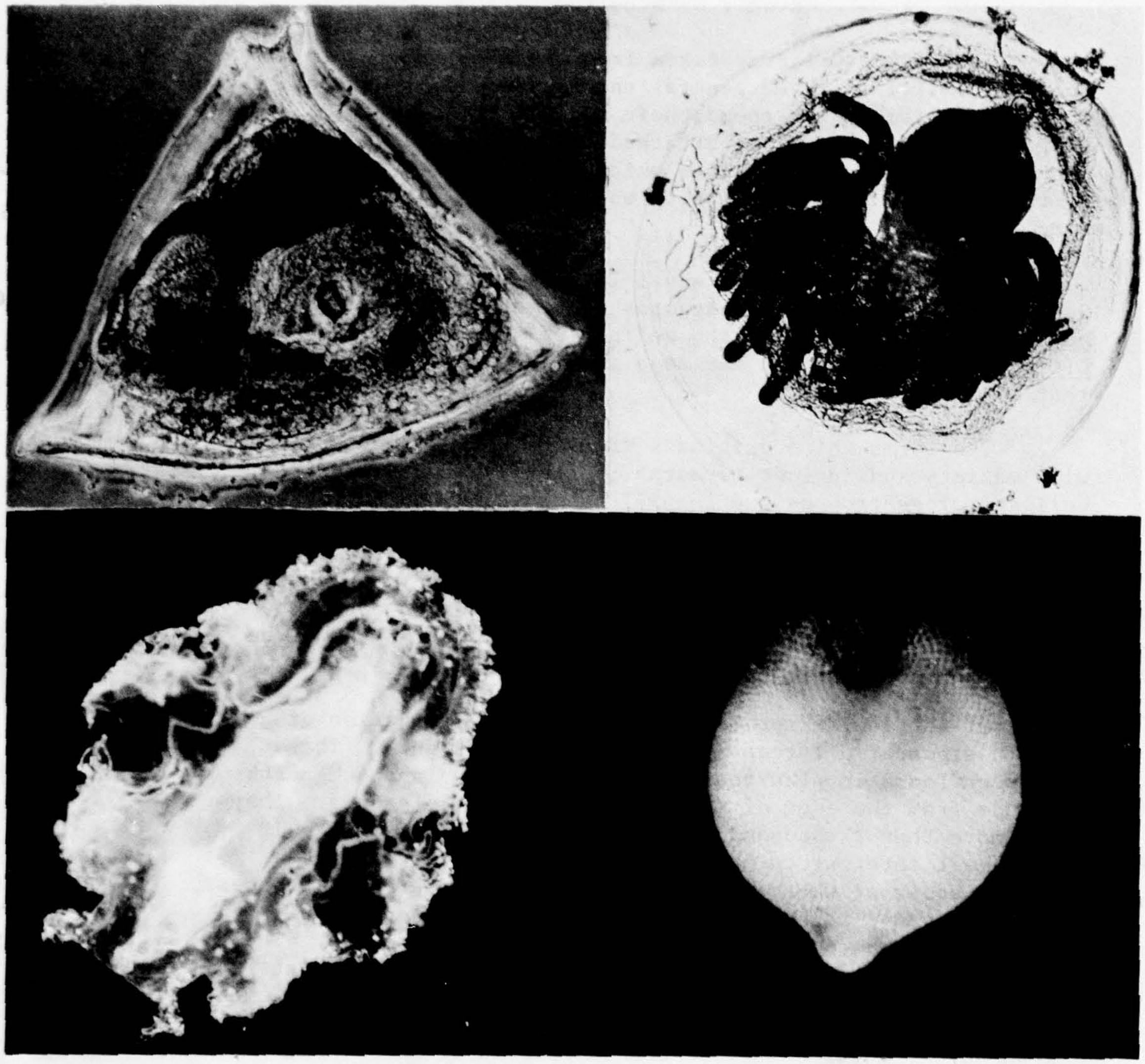

FIGURE 1. LARVAE FROM THE OPEN SEA TAKEN EAST OF THE GULF STREAM ON A TRANSECT FROM LONG ISLAND TO BERMUDA.
Upper left: CYPHONAUTES LARVA OF Membranipora tuberculata (?);
Upper right: LARVA OF AN UNIDENTIFIED INARTICULATE BRACHIOPOD;
Lower left: "GIANT AURICULARIA" FROM AN UNKNOWN SEA-CUCUMBER;
Lower right: LARVA FROM AN UNIDENTIFIED SIPUNCULID. THIS FORM HAS BEEN FOUND ON A WIDE AREA OF THE ATLANTIC.

The very laborious task of separating and identifying this material was very much accelerated by the help of a summer assistant, Miss Janet Rodman of Bryn Mawr College. Certain forms such as the Scalibregmidae, a family of polychaete worms, are now known to be present in sufficient numbers and are identifiable so that the study of periodicity of reproduction by the examination of histological preparations can proceed. Other questions such as the incidence of hermaphrodism and asexual reproduction will be determined among various species of the benthos. A knowledge of reproduction and planktonic development among deep-sea benthos is necessary for an understanding of speciation and evolution in the deep sea.

The study of the larvae of New England intertidal gastropods was continued in collaboration with A.H. Scheltema. A description of the larvae of Nassarius trivittatus grown in the laboratory has been completed and submitted for publication.

BENTHIC COMMUNITY STUDIES

Howard L. Sanders and Robert R. Hessler

The year of 1963 was primarily devoted to the systematic analysis of deep sea fauna of the Gay Head-Bermuda transect. Our efforts centered on three groups: Pelecypoda (Sanders); Isopoda (Hessler); and Polychaeta (Dr. Olga Hartman).

The three major faunal components show essentially similar distribution patterns. No species has a ubiquitous distribution and, in fact, each species is restricted to a specific portion of the transect. These data are consistent with the reasonable hypothesis that the species components of the deep-sea benthos are layered according to depth along the ocean floor.

Of the three groups, the Pelecypoda is the one element that is somewhat adequately known in the area of study, primarily from the efforts of Verrill, Bush, and Dall before the turn of the century. Between 60 and 65 species have been found in the samples so far analyzed. There is strong evidence for a zoogeographical boundary in the region of the Gulf Stream since almost no lamellibranch species were found both north and south of the Gulf Stream. Those present north of the Gulf Stream can usually be placed within a known bathyal or abyssal species occurring at higher latitudes of the North Atlantic and frequently from approximately similar depths. Those species collected south of the Gulf Stream appear to have no North Atlantic affinities.

More than half the specimens by number in our samples are polychaetes. Until the present survey, 500 species of polychaetes were known as the result of one hundred years of collecting from all oceans at bathyal and abyssal depths. Yet from 26 samples in our geographically restricted transect, Dr. Hartman has found about 220 species of which one-quarter are new. In describing some of these forms, it was necessary to erect higher taxons. Dr. Hartman documents the presence of three separate polychaete assemblages along the transect, a Continental Slope association, an Abyssal association, and a Bermuda Rise association. This is the first report of a clear and distinct Slope fauna.

The study of Isopoda found along our transect so far has been limited to the Asellota, because this suborder comprises the vast majority of the isopod fauna at lower bathyal and abyssal depths; indeed, other isopodan types are only rarely present. Thus the Asellota (disregarding freshwater and epizoic forms) characterize the typical deep-sea fauna, whose boundary with that of the shallow-water shelf fauna is between 100 and 200 meters along the transect. This tends to be deeper than the upper limit for comparable species described from the Scandinavian coast, supporting the idea that the upper limit for deep-sea forms is temperature-dependent and is therefore shallower at higher latitudes. Approximately 75 species of Asellota are estimated to occur in our transect samples. More than half of these are probably undescribed species. For instance, the genus Desmosoma is represented by 15 species along the transect. All but four of these are new. (The four known species were described from Greenland or Scandinavian waters.) Previous to our study, the world count for Desmosoma was only 31 species. That such a large percentage of new species could be taken in such a limited area as our transect suggests that at least among the arthropods, the deep-sea benthic fauna is still hardly known at all.

The values for our quantitative studies are appreciably greater than that found in any previous investigation of the deep-sea benthos, raising the possibility that the density of animals present in our region of study is abnormally high. To test this possibility, Mr. George R. Hampson collected samples in April at comparable depths off the coast of South America during the EQUALANT cruise. The numerical results agreed closely with our findings in the North Atlantic.

A summary of some of our results and conclusions regarding the deep-sea benthos can be found in Proc. XVI Intern.Congr.Zool. 4: 311 and AIBS Bull. 13(5): 61-63.

During the past summer in collaboration with Dr. Paul Mangelsdorf, we compared subtidal sediment salinities with that of the immediately overlying water in a small estuary north of Woods Hole, the Pocasset River, and related these findings to the distribution of the estuarine fauna. These data were collected by a Salt Bridge, an instrument developed by Dr. Mangelsdorf. Our findings regarding bottom-water salinities showed periods of high, essentially marine salinities and periods of low, almost fresh-water salinities separated by abrupt and brief transitional periods throughout the upper half of the estuary. The low-salinity phase is of longer duration at the upper end of the estuary with the high-salinity phase gradually predominating as one proceeds seaward. In contrast to the marked fluctuation in bottom-water salinity, the sediment salinities are stable and constant with each station having its own characteristic salinity value and with a gradual increase in salinity from the uppermost reaches to the mouth of the estuary.

The type of salinity regime has a marked effect on the distribution of the benthonic fauna. The epifauna, that component of the benthos that lives on the surface of the sediment and therefore subjected to the extreme salinity fluctuation and rapid and severe rates of salinity change, is very poorly represented, particularly in the upper part of the estuary. The infauna, those animals living in rather than on the bottom, on the other hand, living under much more stable salinity conditions, make up the vast majority of the fauna. It is precisely the rigid periodic short-term fluctuations in the water salinity that stabilize or buffer the sediment salinities and therefore markedly reduce the degree of physiological stress imposed on the infauna as compared to the epifauna.

The first part of our monographic treatment of the crustacean subclass Cephalocarida, dealing with functional morphology, larval development, and comparative external anatomy, has now been published (Sanders, 1963, Mem.Conn.Acad.Arts & Sci.,15: 80 pp.). A second contribution concerning the comparative skeletal- musclature system is in press (Hessler, Mem.Conn.Acad.Arts.& Sci.). Another paper relating to the Cephalocarida appears in a recent symposium volume (Sanders, 1963 in: Phylogeny and Evolution of Crustacea. Mus.Comp. Zool., Special Publication. XIII. Significance of the Cephalocarida: 163-175). In press is a paper dealing with larval development of the Caribbean cephalocarid, Lightiella incisa Gooding from specimens we collected in Puerto Rico (Sanders & Hessler, Crustaceana), as is a note reporting the finding of cephalocarids in 300 meters of water (Hessler & Sanders, Crustaceana).

MARINE COMMUNITY METABOLISM

John M. Teal

Work began with measurements of respiration of various species of tropical euphausids under varying conditions of temperature and pressure. This was done in collaboration with Dr. Frank Carey aboard R/V CHAIN in the tropical Atlantic during February and March. Difficulties with the pressure apparatus were encountered which have been corrected since. In general the results indicated an increase in respiration with increasing pressure which would tend to counteract the effect of decreasing temperature with depth. In other words the metabolism of the vertical migrants tends to remain constant during their migration. We are about to continue these studies with Meganyctiphanes, a euphausid from the Gulf of Maine.

While in the tropical ocean, we also made measurements of respiration of a number of representatives of planktonic groups other than crustacea (salps, heteropods, pteropods, etc.) which are difficult to keep alive and which must be studied soon after being caught.

During the summer and fall, studies were carried out in local salt marshes in cooperation with Dr. John Kanwisher. Plastic tents held up by air pressure, were placed over individuals or groups of Spartina plants and their CO_2 uptake measured over 24-hour periods. Respiration was greatest just after dark and decreased during the night while allowing for variations in light, photosynthesis was greatest early in the morning and decreased during the day. CO_2 uptake continued when plants were artificially darkened in the middle of the day. This was traced to CO_2 uptake by the roots which were drawing the gas down through the stem as they do oxygen. The phenomena disappeared soon after we discovered it so is presumably limited to young plants. We expect to examine it in some detail this spring.

In several cases measurements of transpiration rate were made by drying the air before it passed over the plants and then weighing the water added to the air. These showed that transpiration was proportional to light in a general way. The water transpired was calculated to contain no more than 1-2 $^{o}/oo$ salt by comparing the salt secreted by the leaves with the amount of water transpired. This indicates that Spartina like the other salt marsh tropical plants studied by Scholander, excludes most of the salt at the roots before the transpiration stream gets into the plant. The remaining salt, which is almost pure NaCl, is secreted by the leaves. This would theoretically have the effect of concentrating

all salts in the marsh muds but since some NaCl is lost through the plant, there is actually a relatively greater concentration of other ions in the muds and of NaCl in the water. This change in relative composition was detected in the late summer when the ratio of Na to K was increased from 49 to 51 in the water draining the marsh and decreased to about 45 in water squeezed from the mud. Larger changes could be expected earlier in the season when the grass is growing more actively.

The roots of Spartina are living in an oxygen-free mud and get their oxygen from the upper parts of the plant. Changes in oxygen and carbon dioxide around both top and bottom of plants were measured starting with moist nitrogen around the roots and moist air around the tops. Three times as much oxygen was transported to the roots under these conditions as they required and the excess diffused out into the gas surrounding the roots. Although the rates for plants growing naturally in the mud might be quite different from those measured, it is clear that Spartina can supply oxygen for aerobic organisms living in close association with their root systems.

During the late autumn and winter a study of pCO_2 changes in estuarine waters has been begun as a way of studying rapidly the sum of the biological activity in various waters. By continuously equilibrating the sea water through which the boat is moving with a small gas volume circulating through the infra-red analyser one can make a continuous recording of pCO_2 in the water. With a shallow-draft boat a survey can then be done of local shallow waters where biological activity is intense and such an integrated measure makes it possible to compare the total biological activity in a variety of areas. Some areas which are subject to intensive study by others at the Institution are being included for comparative purposes.

MARINE BIOPHYSICS

John W. Kanwisher and William S. Maddux

The concentration of marine animals and plants varies abruptly on both small and large scales. We have been developing some means of rapidly assessing this inhomogeneous distribution. The animals are counted *in situ* when they interrupt an electric field. The resulting electrical pulses are proportional to volume and can be size-sorted. Animals as small as .2mm give a clearly defined signal. There is no upper limit of size. The animals which have been counted can be retained in a net to check the species composition. We are attempting to monitor phytoplankton concentration with a long path (4 meters) spectrophotometer working at the chlorophyll peak. Past work has shown local sharp variations in CO_2 tension in the surface sea water. We hope the additional information will help explain this in terms of the local plant-animal dynamics.

The central aim of the work on porpoise physiology has been to understand how the smaller cetaceans strike a thermal balance in cold water. It was found by both direct and indirect calorimetry on a harbor porpoise that a high rate of metabolic heat production (3 times man) is necessary if small animals (20 Kg) are to keep a mammalian body temperature (36-38^{o}C). Heart rate was found to vary by a factor of 2, and was most rapid directly after breathing. As this is opposite to what would have been expected, we are building telemetering gear to transmit acoustically from a free swimming animal. The present transmitter (a 60 kc device) has been tried successfully on a skin diver.

In the R/V CHAIN cruise to Brazil, CO_2 tension was measured along the track of the ship. Repeated crossings of the equatorial undercurrent showed that surface water CO_2 does not strongly reflect underlying hydrography, contrary to our expectations. In addition repeated lowerings to 1500 meters were made with polarographic oxygen electrodes. The resulting continuous profiles were substantiated by Winkler oxygen determinations from Nansen bottle samples.

ICHTHYOLOGY

William C. Schroeder

Research was continued throughout the year on skates and rays trawled by U.S.Fish and Wildlife vessels operating along our South Atlantic coast, in the Gulf of Mexico, and southward to the offing of Brazil. In addition to a large amount of material received in 1962, part of it in November and December of that year, substantial collections came to me in May, July and October 1963.

All, excepting a few pending items, are included in a manuscript about ready for publication. However, in December, I was informed that another collection would be shipped in January, 1964. As this was taken chiefly off the coast of Venezuela, and in deep water, it should prove of particular interest and I plan to include the results of its study in the manuscript at hand. Publication is expected to be in the Bulletin, Harvard Museum of Comparative Zoology.

BIOLOGY OF LARGE PELAGIC FISHES

Frank J. Mather, Margaret E. Watson, and Martin R. Bartlett

The continuing growth of the purse-seine fishery for tunas and the long-line fishery for swordfish <u>Xiphias gladius</u> in the northwestern Atlantic facilitated further advances in the study of the yearly distributional and reproductive cycles of these fishes as well as seasonal changes in body condition. Similar investigations of other large pelagic fishes were advanced, along with studies of the visceral and skeletal anatomy of many species and of the taxonomy of amberjacks, genus <u>Seriola</u>.

Field work included over 200 man-days on 10 cruises in four research and commercial vessels in the Atlantic, covering the edge of the Continental Shelf from Cape Hatteras to the Nova Scotia Banks, and extending eastward beyond the Azores. In addition, a cruise of 49 days in the Indian Ocean worked from Mauritius northward into the Arabian Sea, terminating at Bombay. Large fishes were caught on long-line and trolling gear, while larvae and small juveniles were collected with nets. Field collections were augmented by important acquisitions and loans from other research organizations and from commercial fishermen.

Landings of the latter were examined on 18 occasions and over 6,000 tunas were measured by Mr. Gerald Pesch, employed under a grant of the Sport Fishing Institute, and five other project members. Log-book data from fishing vessels were also recorded. The compilation of biometric and other descriptive data continued concurrently with the above activities and also through museum and laboratory visits. Uniform systems of examination were set up with Mr. Noel Tibbo, who directs the swordfish and tuna studies of the Fisheries Research Board of Canada.

Project personnel and cooperating fishermen and scientists marked some 3,400 fishes, and 76 returns were obtained, far exceeding all previous annual totals for the Cooperative Game Fish Tagging Program.[1]

Information on the areal and seasonal distribution of tunas was increased through the above activities. The mid-winter presence of small numbers of bluefin and bigeye tuna and albacore, Thunnus thynnus, T. obesus, and T. alalunga, along the edge of the Continental Shelf from Hudson Canyon to Norfolk Canyon was established for the first time during R/V GOSNOLD Cruise 6[2], and was further confirmed by commercial catches in this area and off Georges Banks and Nantucket Shoals. Long-line exploration was extended for the first time into the central and eastern portions of the North Atlantic by the National Geographic Society-Woods Hole Oceanographic Institution-U.S.Bureau of Commercial Fisheries Pelagic Fish Research Cruise in M/V DELAWARE (Cruise 63-4)[3] April 22 - June 10. Consistent catches between the Grand Banks and the Azores indicated a transatlantic distribution of bigeye tuna in the middle latitudes. A giant bluefin was unexpectedly taken in mid-Atlantic and a few others near the Azores, but our hopes of making a positive contact with the eastern Atlantic population of this species were disappointed. In warmer waters between the Azores and Bermuda, the yellowfin T. albacares was the dominant

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[1]Supplemental financial support for this program was received from the Charles W. Brown, Jr. Memorial Foundation, the International Game Fish Association, the Sport Fishing Institute and several contributions from clubs and individuals.

[2]Vessel use financed by NSF Grant 23472.

[3]One-half of vessel use financed by National Geographic Society Grant to WHOI.

tuna species, and bluefin were encountered as usual in the Gulf Stream and off South Channel. Environmental data including temperature, salinity, chlorophyl, and plankton volumes were gathered for comparison with fishing results. Mr. Bartlett participated in a fall cruise in the M/V DELAWARE (Cruise 63-11), which, like R/V CRAWFORD Cruise 56 in the fall of 1960 found bluefin absent from the deep waters beyond the edge of the Continental Shelf, but supplied new distributional information on yellowfin and bigeye tuna and albacore.

The seine tuna fishery produced record landings due to the participation of some 18 vessels with several times the capacity of previous local fleets, but the catch of bluefin on a unit-effort basis declined from the 1962 level. Increased fishing mortality and a possible diminution of the stock were also indicated by a dramatic increase in tag returns for bluefin in the northwestern Atlantic from 6 for the previous 8 years combined to 19 for 1963 alone. Preliminary analysis of size composition data for bluefin, which will be used in studies of population dynamics in cooperation with the U.S. Bureau of Commercial Fisheries and the ICES bluefin tuna working group, showed no dominant year class in the 1963 landings, in contrast to the preponderance of 4-year-olds in 1962. On the other hand, indications that skipjack, Katsuwonus pelamis, might constitute an important resource, first noted in 1962, were amplified by greatly increased landings and by reports from seiners and their spotting planes of enormous skipjack schools south of Long Island.

The long-line swordfishery, which received much of its impetus from successful experiments conducted in WHOI research vessels May - October, 1962, has maintained contact with this species throughout the year. R/V GOSNOLD Cruise 6 first revealed the mid-winter occurrence of the species in the Cape Hatteras - Norfolk Canyon area after its disappearance from the fall fishing grounds between Georges Bank and Hudson Canyon. Commercial vessels recorded its return to the northerly area in the spring, as well as the seasonal influx of sharks and tunas. Additional measurements and examinations confirmed the attainment of larger sizes by females than males. The sex composition of landings varied greatly, a group wintering off Cape Hatteras included only 3% male fish, contrasting with October findings of equal numbers of each sex off Long Island.

Much progress was made toward publication on the description, identification, taxonomy, and distribution of Atlantic amberjacks, Seriola, with notes on their relationships to Pacific species. Examination of external characters of our very extensive collection, including complete series of each of the 4 North Atlantic and

Mediterranean species, ranging from ten (10) mm, to or nearly to maximum known size for each, and smaller samples of South Atlantic material, including these species and one other has nearly been completed. X-rays and skeletons indicate good possibilities of identifying two species by vertebral counts. Analysis of these data, some of which concern important type and topotypical specimens, should end the long-standing confusion over the nomenclature of Atlantic Seriola. Indo-Pacific specimens and data are being acquired at an accelerating rate, and a world-wide revision of the genus is planned. Gerald Pesch, John Creamer, and Kay Oliphant, a summer research fellow, assisted in this effort. Thirty-three tag returns for the greater amberjack S. dumerili, all from Florida waters, indicated heavy fishing pressure on the species in certain localities, where the overall return rate of 10% was considerably exceeded. None of the recaptures was over 100 miles from the release point, and most of them were in its immediate vicinity.

Eighteen tag returns were obtained from istiophorid fishes. Most interesting among 16 for Atlantic sailfish Istiophorus albicans was the first to record a migration from off southeastern Florida to North Carolina waters. The first Pacific return for this family showed a movement from off La Paz, Baja California, 1150 miles southward to the Equatorial Current area in 72 days by a striped marlin, Tetrapturus audax.

Rare specimens and unusual distributional records obtained from M/V DELAWARE cruises and commercial trips included two additional specimens of the rare pelagic ray Dasyatis violacea, several additional specimens of the gempylid Lepidocybium flavo-brunneum and the opah Lampris regius, a northern record for the longbill spear fish Tetrapturus pfluegeri, and the first western North Atlantic long-line catch of a black ruff, Centrolophus niger.

Early Life History Studies.

Identification of larval tunas by microradiographs continued but for only the first half of the year. Laboratory facilities at the Blake building were moved into the new Laboratory of Marine Science in June. As soon as the X-ray room in this new building becomes operable it will be well-used by many besides ourselves for delineating detailed and accurate skeletal structures in specimens as small as one-quarter of an inch in length to as long as 10 feet.

Larval tunas and istiophorids were obtained on the cruises by dip-netting and plankton tows. With the summer help of Margaret

Anne Spilhaus[1] many larval fish were sorted from mixed collections made on recent cruises. Many valuable specimens were acquired at Messina while enroute to the Indian Ocean Cruise, aboard the R/V ANTON BRUUN in the Indian Ocean and during a visit to the Nankai Regional Fisheries Laboratory in Kochi, Japan. From future X-ray analysis of these specimens we hope to complete the identification of the six species of larval tunas and to solve the problem of the two skeletal types of swordfish.

Maturation Studies.

Gonads of tunas, swordfish, marlins, sailfish, amberjacks, bonitos and dolphins were processed for histological analysis. This accomplishment was made possible by the donation of institutional funds for two summer employees, Margaret Anne Spilhaus and Helen McKenzie[2]. About three-fourths of the specimens on hand are now processed and await analysis.

Anatomy

Macroscopic anatomy of internal organs and skeletons of species collected during recent field trips advanced considerably with the summer help. From these dissections material for growth studies accumulated, e.g., otoliths, scales and vertebrae which await X-raying. Puzzling features of airbladders and urinary bladders in tunas presented themselves during these dissections. For an explanation we turned to the microscopic anatomy found in their histological preparations. Cytologically there were structures present in airbladders of tunas not reported from any other fish, likewise each species differed slightly one from another. Distinctions of habit, habitat and population identity may be discernible from further study of these airbladder differences. We are very grateful for the time and knowledge donated to the problem of airbladders by Dr. Thomas Malumphy during the past summer.

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[1]Support from Nonr-2196(00) NR 083-004.

[2]Support from NSF Grant GB-861.

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CHEMISTRY and GEOLOGY

HAS BEEN FOUND ON A WIDE AREA OF THE ATLANTIC.

DEPARTMENT OF CHEMISTRY-GEOLOGY

John M. Hunt, Department Chairman

HYDROCARBONS IN THE SEA

Max Blumer

A chemical study of zooplankton from the Gulf of Maine has led to interesting results. Pristane (2,6,10,14-tetramethylpentadecane), a low-density hydrocarbon, occurs in a wide range of planktonic animals, which derive it from phytol in their phytoplankton diet. A particularly high pristane concentration is reached in Calanus finmarchicus, C. glacialis and C. hyperboreus, where this hydrocarbon may aid in buoyancy regulation during periods of starvation. Of additional advantage to these cold-water species may be the low melting point of pristane; it would tend to keep the fat deposit in a liquid form. From Calanus, pristane moves through the marine food chain, first appearing in predators feeding on Calanus and then in larger animals like herring, squid, sharks and whales. Recently, it also has been isolated from marine sediments and petroleum. Other planktonic animals, which are poor in pristane may contain other species-specific compounds. It is likely that these compounds find their way into the surrounding water mass at a concentration exceeding their detection limit. This may enable us to follow the movement of such a biochemically tagged water mass in vertical and horizontal direction away from the source.

The solubility of hydrocarbons both in sea water and in the lipids of organisms permits their exchange between various biological and non-biological sources in the sea. In such a way man-made pollutants may become adsorbed on the surface or incorporated into the lipids of marine organisms, especially algae. This causes an uncertainty with regard to the origin of the hydrocarbons isolated from natural plankton sources. In order to define the hydrocarbons actually synthesized by the cells we have constructed and put into operation an apparatus for growing and harvesting marine algae under conditions excluding contamination with hydrocarbons. This experiment should also provide information on the species variability of hydrocarbon synthesis in marine algae and permit a clear differentiation between the recent, biosynthetic hydrocarbons of organisms and the fossil ones of petroleum, fuel and lubricating oils and petrochemicals.

The realization of the wide occurrence of hydrocarbons in the sea has led us to search for them in manganese nodules, highly adsorptive deep marine deposits. The finding of pyrene and fluoranthene, the most abundant aromatic hydrocarbons of sea water, in the nodules lends further support to the idea of an exchange of hydrocarbons between sea water and the media in contact with it.

Pyrene and fluoranthene are a minor fraction of the many compounds which were separated by gas chromatography but not yet identified. We plan to determine the structure of additional organic components of the manganese nodules, to study their survival at the high redox potentials involved and to extend this investigation to other pelagic sediments.

Much can be learned about the conditions that organic molecules encounter in the subsurface from a study of the gradual transformation of reactive biochemicals in the sediments. We have recently shown that the complexity of the hemin and chlorophyll derivatives, which survive in the sediments, is far greater than anyone had anticipated. Each of the forty-odd new pigments which we have identified is the product of environmental modification of a very limited number of original pigments; each compound gives us an indication of the organic processes which occur in subsurface sediments. We plan to investigate in detail several new groups of chlorophyll and hemin derivatives which we have recently isolated; among them a number of unknown porphyrin-metal complexes.

The detailed study of the organic pigments and the hydrocarbons of a fossil sea lily of Triassic age has provided us with one of the best understood sequences of geochemical reactions. A biosynthetic, primary pigment is converted under ring closure to a polynuclear hydroxyquinone which then undergoes gradual reductive elimination of substituents. The final products are a number of unusual aromatic and aromatic-alicyclic hydrocarbons.

Professor L. D. Quin of Duke University, who is spending a sabbatical year at Woods Hole, has isolated an unusual compound containing a carbon-phosphorus bond (aminoethylphosphonic acid) from the local sea anemone <u>Metridium dianthus</u>. This amino acid analogue appears to be incorporated into the proteins of <u>Metridium</u>. The search for this and similar organophosphorus compounds will be extended to other marine organisms.

INORGANIC GEOCHEMISTRY

Vaughan T. Bowen, Victor E. Noshkin and Peter L. Sachs

Low-level Beta Counters

After tests with some, and examination of other commercial counting units advertised to count beta particles with reasonable efficiency and with backgrounds less than 1 count per minute, we decided to design and build our own. The design settled on is a flow counter, with a cylindrical body cut out of 3/8 -inch thick black lucite sheet, the cylinder being 1¼-inch ID. This is lined with 1 mg/cm^2 gold spattered mylar, which is also used for the window. The center wire, across a diameter of the cylinder, is 1 mil stainless steel. The cylinder is drilled on opposite sides with 1/8-inch ports, and the counter operated with Q gas (99.05 Helium, 0.95% Isobutane) as a flow counter, in the geiger-mueller region. Four such units are built together into a package 2 x 2 x 4 inches, the gas flowing in series. Background reduction is achieved by a ring of 13 brass walled geiger-counters (1 3/16 inches by 9 inches) operated in anti-coincidence with the sample counters. The unit is mounted in a shield made of standard 3 x 1½ x 6 inch lead bricks, 3 inches thick, lined with 1/16-inch electrolytic copper sheet. The shield's outside dimensions are 12 x 12 x 24 inches. A new wholly transistorized set of electronics was designed and built for us by Mr. Emil DeAgazio of Stoneham, Massachusetts. Performance has been excellent. The average background rate for the 4 counters over the past six months has been 0.32 $\pm$ 0.04 counts per minute, and very steady. The unit is now being regularly used for counting of fission products from sea water samples from the Pacific. Using standards - Strontium 90 and Cesium 137 - calibrated by the National Bureau of Standards and by the AEC Health and Safety Laboratory, we are now in the process of inter-calibrating our counters at Clark University, Worcester and the new unit at WHOI.

Field Work in 1963

Mention was made in last year's report of our two-ship program about the equator, which was then in progress. In spite of a serious loss of ship time by R/V CHAIN, first because of an accident in Recife harbor, and then because of an early return to join in the THRESHER search, the program was very successful. We are appending below track charts showing the work performed on the last two legs, from Recife to Recife and from Recife to St. Thomas. The first leg, from St. Thomas to Recife is still in process of summarization.

Progress on analysis of the samples and data has been gratifying, if uneven. The survey of subsurface echo-soundings in the Gulf of Paria - summarized below - is currently in press. Dr. Donald Squires of the U.S.National Museum, reported his survey of the Guiana Shelf "Shelf-edge prominences" at the USGA meetings in November; Dr. Squires has also completed identification of the coral specimens collected, and is awaiting our summary of hydrography, navigation, and geology, before preparing this for publication. The Acantharia, Foraminifera and Radiolaria of the plankton collections are in various stages of study at the University of Parma, the U.S. National Museum and U.S. Geological Survey respectively; the pteropods have been sorted, partially identified, and now await shipment to Oregon State University. Study has begun on some of the dredge samples - see below for one aspect - and on several of the cores; the fission product samples are in process of analysis. Much remains to be done, and in some areas, no cooperating scientist has yet been found.

A second short cruise in November - R/V CRAWFORD - was made. In addition to large volume fission product samples, this resulted in some collections of shelf sediments for fallout analysis, large plankton collections and tests of new instrumentation (see below under "Gulf Stream" and under "Free Fall Coring Device").

Distribution of Fallout Fission Products in the Atlantic Ocean

The surface water collection program from the U.S.-manned weather ships, mentioned a year ago, has been continued with considerable success. Because of the loss of production in moving to our new laboratory, and the pressure of other samples from the research cruises mentioned above, completion of analyses has lapsed far behind the sample collection. The Sr^{90} analyses for all the samples whose lanthanide analyses were discussed last year, are now in hand. In general the sets of data are remarkably concurrent, though the patterns are revealed in enough detail that we can often see the rapid separation from strontium of the lanthanides, as we have previously postulated. The changes in surface concentration of Sr^{90} during summer, are quite interesting: at 35°N, 48°W, an increase of over 100% from April 15 to July 15; at 44°N, 41°W an increase of barely 50% from April 15 to July 1; at 52°15'N, 35°30'W, an increase of just 100% to July 15, and no subsequent increase to September 1; at 56°30'N, 51°00'W, an increase of about 20% to July 1. Receipt of comparable analyses of precipitation at the two intermediate positions, permits us to conclude that these variations are both hydrographic and in rate of supply. Unfortunately the precipitation data is still quanti-

tatively enigmatic, and unavailable from the far northern and southern stations. It is anticipated that 1965 will see, however, an improvement in the collection of this important collateral data, both in respect to coverage and to its quantitative expression. It is also to be hoped that collection of large volume sample stations in the area 40° to 55°N, and 27° to 49°W, on the current ATLANTIS II cruise, will clarify the interpretation of the surface sample data.

An illustration of such clarification is offered by the Sr^{90} from Erica Dan Station 237, II-26-62 at 57°40'N, 48°00'W, the closest obtained to Weather Station B. The hydrographic station shows the water column approximately isopycnal down to 800 m; Sr^{90} concentrations are:

0 m	11.4 $\pm$ 1.0
100 m	12.2 $\pm$ 0.7
300 m	12.7 $\pm$ 0.7
500 m	11.5 $\pm$ 0.6
800 m	14.0 $\pm$ 1.0

In contrast, the samples from 1500 and 2000 m, a layer slightly colder and more saline, show respectively 7.2 $\pm$ 0.6 and 6.1 $\pm$ 1.3; that from 3300 m, almost 2°C colder still, shows 10.1 $\pm$ 1.4. It is clear that surface concentrations in this area must be explained in terms of homogenization by mixing down to about 800 m, occurring rapidly in relation to the rate of fallout to the surface. Equally, no water has been seen of Sr^{90} concentration below 50% of the value for the upper layers. The data is clearly consistent with Worthington's hypothesis that deep water in this part of the Labrador Sea has left the surface more recently than has that at intermediate depths. A sharply-contrasting profile, still incomplete, was obtained from the same cruise at 59°23'N, 26°01'W, IV-17-62. Here the water column shows a regular increase of density with depth, and the Sr^{90} decreases by 1/3 from surface to 500 m, by 1/4 again from 500 to 800 m. Sr^{90} is not detectable by our method at 1500 m, but again is approaching shallow-water values at 2000 m.

In September 1959 we attempted to obtain a series of samples through the Gulf Stream and into the southward-flowing undercurrent beneath it, postulated by Stommel and demonstrated by Worthington and Swallow. A Sr^{90} profile was obtained showing high values (10 and 13 dpm per 100 L.) at surface and 300 m, a minimum of 2 at 500 m, and then increasing to 3 at 800, 3.5 at 920 and 6.6 at 1400 m. Unfortunately the sampler pretripped on

the lowering to 2700 m. In 1961 several stations were made, again in September, to confirm this result. Profiles are not precisely reproduced, but one station through the Gulf Stream shows a minimum at 1500 m (Sr^{90} concentration below detection limits) with a value of 4 at 1960 m, and a second station, 18'N and 31'W of the first, shows Sr^{90} below detectability at 1000 m and up to 5 at 1500 m. Attempts in 1963 to repeat this sampling program ran into especially inclement weather, resulting in stations of only partial usefulness.

<u>Fallout Measurements in the Chukchi Sea</u>

We have now determined Sr^{90} on Chukchi Sea samples collected in August of 1959, 1960, 1961 and May 1962. As noted in last year's report, the 1959 samples showed the Sr^{90} levels to be expected from direct delivery at that latitude. The 1960 and 1961 concentrations, however, are very much higher: 65% and 100% respectively. Since these samples represent the period of the moratorium on atmospheric testing, during which surface deliveries were minimal, the increase is best explained by the hypothesis that these samples were taken during passage through the sampling area of highly-contaminated Pacific water. Since the volume of the entire Chukchi Sea approximates only $20 \times 10^3 km^3$ and the northward-flowing current approximates $40 \times 10^3 km^3$, it seems to us unlikely that the high values would prove to represent average concentrations during 1960 and 1961. Rather we believe these represent two separate injections of a possibly larger series of injections. The 1962 value is within the range reported by Aarkrog of Denmark for near-shore samples both around Denmark and around Greenland, so may well mark a return in the Chukchi Sea to the fallout level due to direct local delivery.

<u>Sedimentation in the Gulf of Paria during the Holocene Transgression</u>

A subsurface acoustic reflection study has been carried out in the Gulf of Paria with an Edo UQN echo-sounder and a Precision Graphic Recorder of the Alden Electronic Equipment Compnay. Using a very short ping-length for maximum resolution, penetration below the bottom in excess of 0.03 sec. (45 m) was commonly obtained in water depths up to 100 m.

The acoustic profiles show three regionally correlatable erosional surfaces separated by bedded sediments. The lowest and middle surfaces join at 43 m below present sea level, the middle and upper surfaces at 20 m. It is postulated that these surfaces were produced by the late Pleistocene regression and two subsequent temporary regressions, from 43 to 62 m and from 20 to 37 m respectively,

which, according to studies in the Gulf of Mexico, interrupted the Holocene[2] transgression.

The depositional sequences show widespread inclined bedding. The lithologic nature of the beds is unknown. The distribution of inclined beds shows that throughout most of the post-Pleistocene interval, sediment dispersal originated uniformly from all basin margins. The present dominant role of the Orinoco appears to have been established very late.

This study was carried out in cooperation with Dr. Tj. van Andel of Scripps Institution.

Novel Mineral Assemblages from Samples near the Mid-Atlantic Ridge

The curious assemblage of the CHAIN 35 Dredge 11 rocks has been investigated. Twenty-one per cent of the material consists of white tabular masses of sepiolite associated with a laminated light brown clay. Montmorillonite and clinoptillolite are present in the clay. Rounded, much weathered brownish cobbles and pebbles of serpentinite containing mostly antigorite constitute 37% of the dredge haul. They typically contain relatively unaltered crystals of orthopyroxene and diopside, and are traversed by calcite veins. One angular, slickensided cobble consisting primarily of granular magnetite with minor amounts of serpentine, accounts for 31%. The remainder of the dredge haul consists of loosely consolidated coccolith ooze. Most of the sepiolite and the coccolith ooze is traversed by worm burrows, and thinly coated with a manganese crust on at least one side and within the burrows. The serpentinites as well are usually coated with this material.

Although experimental data and theoretical considerations suggest that sepiolite should be found, it has not been reported previously from a modern deep oceanic environment. It may be expected as an alteration of serpentine with which it is often associated elsewhere. Dunites and serpentinites have been dredged north of this location, closer to St. Paul's Rocks, but no sepiolite was found associated with these samples. Even in this dredge the sepiolite is never found in direct contact with the serpentine or indeed any other mineral except for those in the brown clay or the manganese crust. In this occurrence it is sometimes interlaminated with or present as veins in the brown clay. It is not clear, therefore, whether the sepiolite of this sample has a sedimentary or hydrothermal origin.

Clinoptillolite is present in the brown clay in small crystals. Usually this mineral is associated with other zeolites in basalts

and its occurrence here is compatible with that of volcanics dredged in this area. It is probably secondary, and might result from the devitrification of volcanic ash. The mineral has not been reported previously from deep-sea deposits.

Design and Testing of a Free Corer

Development continues on a free corer which can obtain a sediment sample without the use of a winch or long wire. The device consists of an expendable weighted core tube and a recoverable float which brings the core to the surface in a plastic liner. Although this is not a new idea, a number of difficulties both technical and economical have to be resolved. A suitable mechanism which would release the liner and float from the expendable weight was designed and tested. An inexpensive pressure-proof light and battery to aid recovery of the instrument at night was required. Provisions were made for containing and supporting the 90-pound gasoline float of the corer to permit more convenient handling.

Two prototypes were field-tested in shallow water on a bottom ranging from sand to soft organic ooze. Divers observed and photographed some of the tests.

Six units were then tested at sea, one each on the continental shelf and slope, and four in deep water. All six floats were recovered easily in sea states ranging from 2 to 4. Of these, one core was lost when the float surfaced under the ship and another when the fastener between the float and the core liner failed. Four 7.5 cm-diameter cores ranging from a 15 cm coarse sand sample to 75 cm of clay were recovered.

The major difficulty emphasized by these tests at sea was one of handling a relatively heavy weight nearly half of which was in the form of a soft, flexible bag filled with gasoline. The latest design is a much more compact and lighter unit incorporating hollow glass spheres as flotation.

Safety Device

A hydraulically-actuated safety device has been built and has proved very effective. The device may be used to reduce accidental premature operation of oceanographic samplers. It consists of a cylinder, a piston and a shear actuated by the piston. Increasing hydrostatic pressure acting on one side of the piston shears a pin at a predetermined depth, thus arming instruments sensitive to sudden motion. In addition to its

original use in connection with piston coring gear, this safety device has been adapted for use with our large-volume sea water samplers, and with Dr. Blumer's new sampler to collect water samples uncontaminated with organic materials.

Alkaline Earth Separations

The separations of calcium and strontium by fuming nitric acid, which we have employed, and that by oxalic acid as has been done elsewhere, are accompanied by some hazard, are time-consuming and are of far from uniform reliability. We have devoted some effort in the past year to development of ion-exchange separations based on the absorption of an alkaline earth mixture from a solution at pH 4.7 onto a column of Dowex 50 x 12. At this pH, and with NH_4^+ concentration kept below 0.4 M, Mg is not absorbed, and the heavier alkaline earths are quantitatively retained. Selective elution of calcium is then achieved with 0.05 M EDTA at pH 5.1, maintaining NH_4^+ below 0.3 M Selective elution of strontium follows with 0.03 M. DCYTA (Dicyclohexane diamine Tetracetic acid) at pH 6.5, with NH_4^+ below 0.3 M. Conditions for selective separation of the remaining barium and radium on the column are still being explored. In each case so far studied, as noted above, ammonium concentration is critical, selectivity of elution being quickly lost as concentrations rise above the maxima noted.

The method as outlined has been used for quantitative estimation of calcium and strontium in carbonate samples counted for Sr^{90} content. In this case, each element is eluted with a measured volume of a standard solution of the appropriate complexing agent; the column is then washed with water and the excess complexing agent is determined by back-titration with standard calcium solution, using phthalein purple as indicator. This has proved to be very quick, and capable of high precision. We intend shortly to present it as a general method for alkaline earth analysis in natural materials including sea water.

Using larger columns, the method has been convenient for separation of strontium in 100 mg amounts, from the calcium and other interfering ions in 500 ml samples of sea water. This problem has been encountered in the radiochemical analysis of sea water from the Pacific, highly labelled with radioactive fission products. The use of still larger columns - containing up to one kilogram of resin - is permitting separation of gram quantities of strontium from as much as their own weight of calcium. When perfected this will permit us to abandon nitric acid separations, even in purifying the strontium from out 55-liter samples of Atlantic sea water. A major problem at this stage is that Dowex 50 is normally contaminated

with amounts of Sr^{90} which are large compared to our low-level samples. Tests are now being conducted - counting of the samples in progress - to see how much of this Sr^{90} contamination is eluted under the conditions described above. Meantime a sample has been secured of Dowex 50 from a new production method thought to yield a much less contaminated product; tests are now also in progress on this.

CHITIN SYNTHESIS

Francis G. Carey

A wide variety of marine organisms have skeletons composed of the polysaccharide chitin and a hardened protein, arthropodin. Growth in many of these animals is synchronized with the shedding of the old shell and synthesis of a new one. A study of the enzymes which synthesize chitin will be an important contribution to our knowledge of the physiology and biochemistry of these animals and may give an insight into the hormonal control of growth in arthropods.

An enzyme which catalyzes the formation of chitin has been prepared from the mold *Neurospora crassa* (Glaser and Brown, 1957). At the onset of these experiments this enzyme had not been studied in animal material; however, some work on a chitin synthetase prepared from insect cuticle was reported in a letter to *Nature* last summer (Jaworski *et al.*, 1963)

The immediate precursor of chitin is a nucleotide sugar, uridinediphosphate-N-acetylglucosamine. The enzyme transfers the acetylglucosamine moiety from the nucleotide sugar to a preformed chitin molecule (the primer), increasing the length of the chitin polymer by one unit.

During the past year C^{14} acetyl labeled uridinediphosphate-N-acetylglucosamine was synthesized and has been used as a substrate in assaying for chitin synthetase prepared from the epidermis of molting crabs and from brine shrimp larvae. The enzyme activity is in a subcellular particle sedimented by centrifugation at 140,000 x gravity. It is assayed by incubating it with the proper salts, buffer, primer and the above radioactive substrate. Activity of the enzyme is measured by the amount of radioactivity incorporated into insolubie material at the end of the incubation. This radioactivity remains in the insoluble material after extensive washing with acid, ethanol and ether. When the insoluble material

is digested with a chitinase prepared from emulsin, C^{14} acetylglucosamine is the only soluble radioactive product found on chromatography of the digest. This indicates that the labeled material is indeed chitin, but definite proof awaits further experimentation.

The enzyme is most active when prepared and assayed in the presence of 0.5 N NaCl. It has a pH optimum of about 7.7. The addition of chitodextrins, short, soluble fragments of chitin molecules, as primer for the reaction stimulates the enzyme about twofold. The presence of such primer in the reaction mixture may be an absolute requirement for the enzyme, but the crude enzyme preparation used at present probably contains too much chitin and chitodextrin to demonstrate this. Various size chitodextrins prepared by acid hydrolysis of chitin and isolated by chromatography on sephadex columns are being tested for effectiveness as primers. The crustacean enzyme is being compared with a similar enzyme from the mold Neurospora for the effect of various factors on its activity.

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CHLORINITY OF SEA WATER

Dayton E. Carritt

During the summer of 1963, an MIT fellowship student, Robert Rodstrom worked with me on the coulometric measurement of total halides in sea water. This work was started for two reasons. First, there is a continuing need for chlorinity measurements of high precision and accuracy. Coulometric techniques are capable of both precision and accuracy at the part-per-million level. If successful, coulometric measurements may provide a means of estimating the chlorinity in terms of fundamental electrical properties and time. Second, there is a potential usefulness in learning more about the notion of "constancy of relative proportions" of major dissolved constituents in sea water. The reasoning here is that the ratio of total anions (or cations) to chlorinity should provide a gross (but not unambiguous) measure of "relative constancy". By measuring first the chlorinity and then the chloride concentration after conversion of all anions to chloride (anion exchange resin techniques) an estimate of the desired ratio could be obtained.

By the end of the summer of 1963, Mr. Rodstrom had constructed a coulometric device that showed reproducibility (precision) of one part in several thousand. Several refinements are now obvious and it is believed that the device can be "debugged" to provide the needed accuracy as well as precision. It is hoped that a summer fellowship student will be interested in continuing the work in the summer of 1964.

ANALYSIS OF SEA WATER FOR TRACE METALS

Dayton E. Carritt and John P. Clarner

Most dissolved inorganic sea water constituents are present in concentrations below the usable limits of conventional analytical techniques. Consequently, some kind of preconcentration is necessary before analyses can be performed. A small ion exchange column has been developed which is capable of concentrating the ions from several thousand liters of sea water. The equipment is simple. It can be arranged to minimize contamination, and it is not affected by the ship's motion.

The method consists of treating the hydroxide form of Dowex 1 with an ammoniacal solution of dithizone to make the dithizone form of an anion exchange resin. The literature lists 18 reactive elements that form stable dithizonates. All of these occur in sea water in trace quantities, i.e. micrograms per liter and less. We have measured column capacities relating column size and geometry, method of preparation of packing material, to the quantity of element that can be removed from sea water using both natural and artificial sea water. For the elements zinc, copper, cobalt, nickel, cadmium and lead, columns approximately 1 x 10 cm have capacities of several thousand liters of sea water. At present we are using a sample size up to 20 liters, with 8 liters (large plastic Van Dorn sampler) being handled routinely at sea. Later the columns are treated with strong HCl to yield a concentrated solution of the metals which can be analyzed polarographically or by other means.

The use of resin-dithizone (R-Dz) columns as collectors for trace constituents in sea water is part of a program which ultimately should provide a better understanding of the geobiochemistry of some of the minor elements in the sea. At present we seem to have solved two of the three major technical problems encountered in the measurement of the six elements noted above. We think of these elements in sea water in <u>particulate form</u>,

that is as a constituent of suspended inorganic minerals, of plankton, and of detritus; as <u>dissolved</u> <u>inorganic</u> <u>species</u>, and as <u>dissolved</u> <u>organometallic</u> <u>species</u>. In our present procedure a sea water sample is led from the sample bottle through a Millipore filter and then through an R-Dz column. Analysis of the filter provides an estimate of the quantity of each element in the particulate form. Analysis of the column elutant gives the quantity present as dissolved inorganic. Actually the latter probably is an estimate of the "exchangeable fraction" where exchangeable must be defined in terms of the relative stabilities of the complexed forms in sea water and of the metal-dithizone complex. As yet we have made no attempt to measure the organometallic fraction, which according to only a few measurements by another worker may account for up to 90% of the total present in sea water. An M.I.T. student who will probably receive his Ph.D. in June is interested in this problem and he probably will attempt measurements of "total inorganics" by neutron activation techniques, thereby allowing an estimate of "organometallic" by difference.

A sea-going technique using M-P filters and R-Dz columns has been tested during a short cruise on R/V CRAWFORD and work on R/V ATLANTIS II cruises on 17 March to 11 April and during the fall is planned. Both R/V ATLANTIS II cruises will be in the North Atlantic.

EQUILIBRIUM BINDING STUDIES OF TRACE METAL COMPLEXES TO VARIOUS CLAYS

Alvin Siegel

The purpose of this study is to understand the effect of the presence of complexing agents on the interactions between clays and trace metal ions in a sea-water environment. The complexing of a metal ion by an organic molecule may result in an increase or decrease in the uptake of that metal by clay particles or sediments depending upon the affinity of the clay for the metal ion, the organic molecule and the various complex ion species formed.

The relatively simple system, zinc glycine, was chosen as a starting point for investigation. Our previous studies on this system, using nontronite 33A and montmorillonite 19 in a mixed electrolyte system of $NaCl$-Na_2HPO_4, had shown evidence of high uptake of the zinc-glycine$^+_1$ species. These studies were extended

to include other montmorillonites and several new clays, illite and kaolinite. In addition, experiments were performed with clays in another mixed electrolyte system, $NaCl-Na_2CO_3$. On the basis of the assumption that only the zinc-glycine$_1^+$ complex binds, a binding constant, β, was calculated for each clay.

$$\text{Where } \beta_1 = \frac{[\text{zinc-glycine}_1^+] \text{ clay/gm}}{[\text{zinc-glycine}_1^+] \text{ solution/ml}}$$

β_1 is quite high for all the clays and in some cases (kaolinite and montmorillonite 20) indicates that the uptake of the complex is as strong as is that of the divalent zinc. In the glycine system it appears that the second complex zinc-glycine$_2^0$ does not bind very readily and so for a clay-zinc system the net effect of the addition of glycine is to decrease the uptake of zinc by the clay, although by at least one to two orders of magnitude less than would be expected on the basis of the stability constants of the zinc-glycine system. Another important effect is that the uptake of zinc by the clay is essentially all in the form of the first complex.

As a check on the value of our stability constants, determined by a titration method, distribution runs were performed with zinc tracer, glycine and anion exchange resins. In these systems the positive zinc-glycine complexes would not be expected to bind. The experimental curves matched the theoretical curves, confirming the values of the stability constants.

These experiments are being extended through the use of other amino acids of varying structural types. It is expected that the binding relationships of their complexes to clays will give us some better understanding of the nature of their binding to clays. The study of other trace metals is being developed. The stepwise stability constants of the cobalt-glycine system were determined in 0.7 M NaCl at 15°C by a titration method. The log of the stability constant for the formation of Co-glycine$_1^+$ was found to be 4.63, and the all-over stability constant for the formation of Co-glycine$_2$ was 8.21. Through the use of these stability constants it will be possible to compare the binding of the cobalt complex to that of the zinc complex in all the clay systems and perhaps come to some conclusion as to specific ion effects in binding of complexes to clays.

PHYSICAL CHEMISTRY OF SEA WATER

Paul C. Mangelsdorf, Jr.

As a part of our research on the fundamental physical chemistry of sea water and similar solutions we have begun investigations of the conductivity of concentrated electrolyte solutions. The work was begun during the summer by Mr. John Wexler, a Summer Fellow, who studied the effects on the conductivity of sea water of added increments of the various electrolyte components.

These preliminary data have not yet been properly interpreted but they have been checked and shown to be internally consistent. In addition, Mr. William Fitzgerald has run a three-way check of our calibrations against those of the Schleicher-Bradshaw salinometer used for salinity determinations at WHOI, against the early work of Thomas, Thompson and Utterback (1934), and against the primary conductivity standards of Jones and Bradshaw (1933). These checks also proved consistent.

The development and use of long salt-bridge methods for marine potentiometry has continued to be a major part of our research effort. In February, Mr. Fitzgerald and I participated in CHAIN cruise 35 on the EQUALANT Expedition. During this cruise we made eleven vertical GEK measurements on the equatorial undercurrent system which, though noisy, gave reasonable transport figures. Salinity profiles with the salt-bridge salinometer were attempted during the early part of the cruise but were only intermittently successful. However, the experience in "debugging" these measurements proved exceedingly valuable for all subsequent salt-bridge work.

During the summer we joined Dr. Howard Sanders in a salinity study of the Pocasset River estuary, using the salt-bridge salinometer. The full capability of the instrument was developed in a sequence of detailed, informative, and highly successful measurements. The salinity microstructure of the estuary waters during various phases of the tidal cycle was surveyed first. This was followed by a set of continuous 24-hour records at various spots comparing the <u>in situ</u> mud salinity with the <u>in situ</u> salinity of the overlying bottom water.

Later the salinity profiles of core samples taken from the mud were determined with the same instrument. This capability of direct <u>in situ</u> salinity measurements in interstitial waters of sediments is one of the particular advantages of this salinometer.

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A transport study of the Cape Cod Canal was made using the horizontal salt bridge GEK. After 2½ days the current carried away our line but the data obtained meanwhile were the best we have ever taken with this system. A method of direct electrical calibration of the Canal by introducing an artificial dipole field from the ASTERIAS was also quite successful.

Simultaneous temperature and salinity records on the canal waters permitted us to observe the unexpectedly complicated process of mixing between Cape Cod Bay and Buzzards Bay. The net transport, which we had expected to be from Cape Cod Bay to Buzzards Bay, proved to be the reverse, if anything. This was due, perhaps, to prevailing winds from the southwest.

Theoretical work on molecular properties of liquids resulted in a successful direct interpretation of the Stokes-Einstein relation for molecular diffusion in terms of velocity fluctuation-regression and autocorrelation. This theory was an outgrowth of a continuing inquiry into the contribution of velocity and composition fluctuations to the conductivity of fused salts and concentrated electrolyte solutions.

GEOLOGY 1963

John M. Zeigler

Publications (other than for COLLECTED REPRINTS) and Manuscripts (to be included in COLLECTED REPRINTS subsequent to 1963)

Zeigler, J.M. Hydrography and Sediments in the Gulf of Venezuela. J.Limnol. and Oceanog. (in press)

Zeigler, J.M., S.D.Tuttle, H. Tasha and G.S.Giese. Geological History of Outer Cape Cod. Geol.Soc. America. (in press).

Giese, G.S., 1963. Billingsgate Shoal. Oceanus, Sept.1963.

Zeigler, J.M. and W.D.Athearn. Hydrography and Sediments of the Gulf of Darien. Advanced preparation.

Zeigler, J.M., S.D.Tuttle, H. Tasha and G.S.Giese. Residence Time of Sand on Beaches. Advanced preparation.

Zeigler, J. M. Modern Beach Studies - - A Review. Oceanography and Marine Biology: an annual review, Vol.2. (in press)

Half of my time this year was spent on leave of absence to the Republic of Colombia where I served as Director of a small laboratory which was being established. The staff of the geology group continued work on programs as outlined below.

Field Work

Two major field experiments were undertaken. The first took place on outer Cape Cod and was designed to obtain data concerning the distribution of velocities within a breaking wave and also to measure the attenuation of surf height and length close to the beach. Breaking waves damaged out instruments and limited the results.

A second major field experiment was conducted on the island of Saint Martin where we hoped to repeat the breaker experiment and add to them studies of ripples formation beneath oscillatory waves. Data collection on ripple formation was excellent. The ripples showed very rapid regeneration under existing sea states, reforming completely in 5 minutes at a depth of 4 feet, in 45 minutes at a depth of 9 feet and in 3 hours at a depth of 12 feet. The instruments failed before breaker experiments could be repeated.

Major Studies (Zeigler, Miller, Tuttle)

Physics of shoaling waves continues to be the point of major interest. Much of our time has been used to interpret past records. Just prior to the move of the computer to the Laboratory of Marine Sciences we obtained a readout of some of our magnetic tapes in very satisfactory form. We continue to examine the data on hand and interpret it in manuscript form suitable for publication.

Field work on Cape Cod has led to some exciting conclusions. We have determined that the outer Cape was deposited as outwash from glaciers between 20,000 and 26,000 years before the present. So far we know these are the first carbon dates of Tazewell age in New England. These absolute age determinations provide a framework within which the post-glacial geology must fit.

Laboratory Studies

Several lines of laboratory research were pursued. A system for placing the data output of the Woods Hole Rapid Sand Analyzer on magnetic tape suitable for computers was developed. The components necessary for this operation are either on hand or ordered. Results from this analyzer continue to cause widespread interest.

COASTAL AERIAL PHOTOGRAPHY
and
BATHYMETRY OF THE TONGUE OF THE OCEAN, BAHAMAS

William D. Athearn

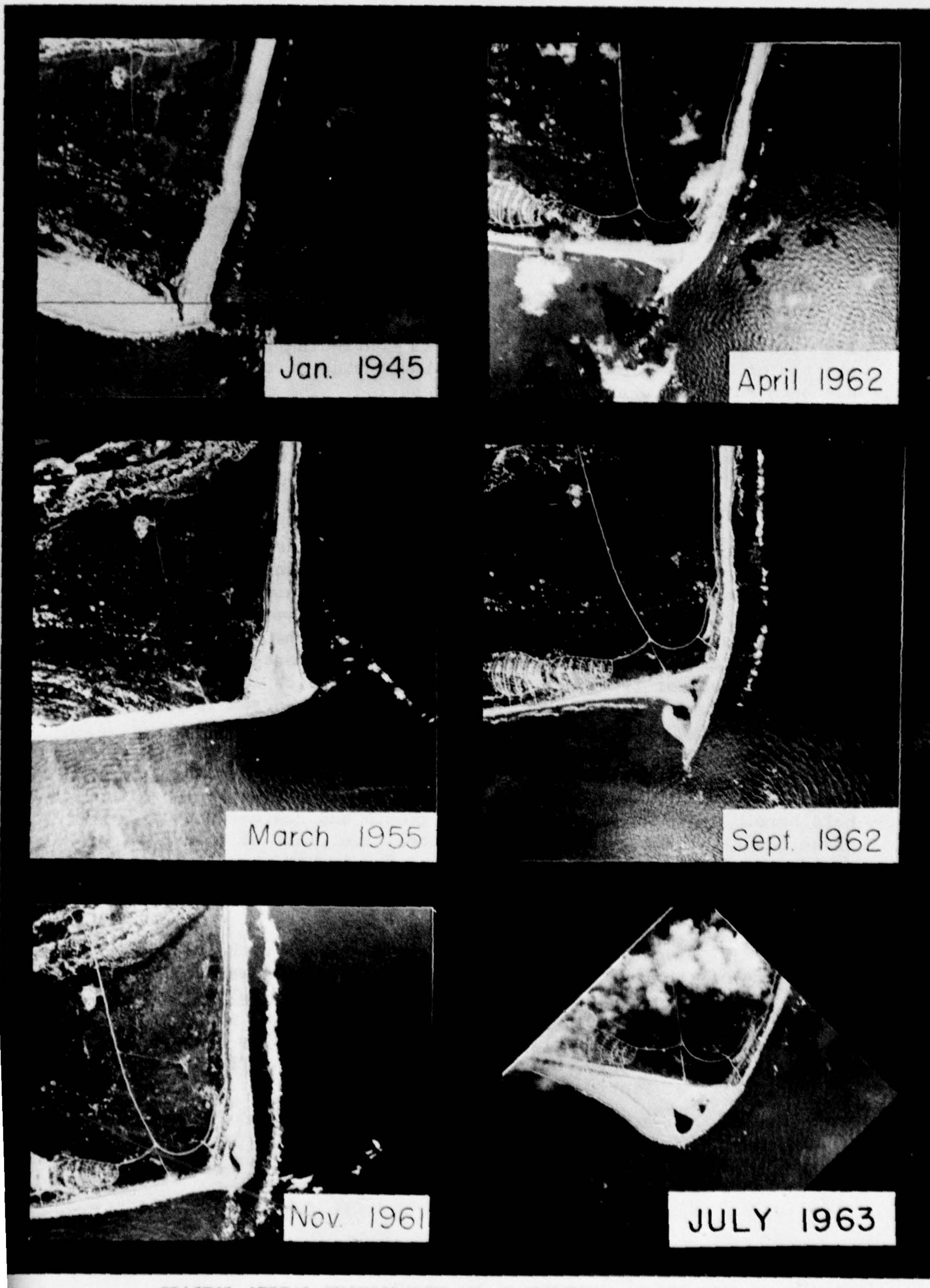
Documentation of changes along the coastline of the eastern United States by means of aerial photography was started at WHOI in 1954. Since then, flights have been made periodically along various sections of the coast between Eastport, Maine and the Rio Grande, Texas. Most frequent coverage has been given those areas of the east coast most affected by storms, i.e. between Cape Cod and northern Florida. In July a flight was made with the Heliocourier during which vertical photographs were taken of most inlets and capes between Montauk Point, N.Y. and St.Helena Sound, S.C. In November a color time-lapse movie was made of the coastline of Puerto Rico from the C54Q Research Aircraft. Beach coverage was not as wide as desired during this flight because clouds forced the plane to fly at lower than optimum altitudes. All of the coastal color movies to date and most of the black-and-white verticals and obliques have been catalogued and filed so that they are readily available to other investigators as the need arises.

A paper entitled "Shoreline Changes at Cape Hatteras" by W.D.Athearn and F.C.Ronne was published in Naval Research Reviews in June. This study was based on a comparison of vertical photographs of Cape Hatteras and Hatteras Inlet, N.C. taken over a seventeen-year period. The earlier photographs were provided by the U.S.Coast and Geodetic Survey and the more recent ones are from our collection. In general, it appeared that within this period (1945-1962) the easterly-facing beach at Cape Hatteras had remained more or less static while the southerly-facing beach had been cut back to the extent of about 1800 feet, mostly prior to 1958. More recent photographs (April and September, 1962) showed a spit building to the southward and filling put toward the westward

in the vicinity of the area of greatest loss since 1945. Photographs from the July 1963 flight, made subsequent to publication of the paper, show that a great quantity of sediment has been deposited to the westward of the spit (see figure) suggesting that if prevailing conditions are not reversed, the southerly beach will be nearly back to its 1945 position.

Historical records indicate that Hatteras Inlet, 12 miles southwest of Cape Hatteras, has migrated about a mile southwesterly in the past 100 years. The photographs from the 1945-1962 period show that this trend is continuing inasmuch as the tip of Ocracoke Island at the southwest side of the inlet has been cut back about a mile in this period. The main channel of the inlet is still near its 1945 position and cut-off segments of Ocracoke Island still remain as islets and shoals, but these are disappearing gradually and the spit to the northeast (Hatteras Island) side of the inlet is slowly growing southwestward. Dr. Sherwood Tuttle and I landed at Hatteras during our flight in July and took a first-hand look at this spit. The older, inner part consists of a sequence of concentric, curved dune-ridges (inlet-marginal ridges), convex toward the inlet. These stand ten to fifteen feet above the intervening swales and are spaced about 150 feet apart. They are topped by a moderate growth of beach grass which tends to stabilize them. The two or three outermost have appeared since 1945, the most recent being that nearest the inlet. The outer spit, which is rather flat and low, rising only about five feet above mean sea level, is swept by high waters during severe storms. Scattered on this surface for a few hundred feet beyond the line of curved ridges are some incipient dunes formed by deposition of wind-blown sand among clumps of grass which have gotten a foothold here. Apparently it is from the growth and coalescence of these dunes under favorable circumstances, i.e.,lack of a severe mauling of the lower spit by storm waves for two or three years, that the inlet-marginal ridges result, and in this way the tip of the island advances toward the inlet.

A WHOI Blue-Cover Report primarily concerned with the bathymetry of the Tongue of the Ocean, Bahamas, which was completed in 1962, was revised and published in 1963 in _Bulletin of Marine Science of the Gulf and Caribbean_. This was published as the second of a series of papers, prepared primarily by workers at the Marine Laboratory, University of Miami, on the "Bathymetry of the Straits of Florida and the Bahama Islands".



COASTAL AERIAL PHOTOGRAPHY AND BATHYMETRY OF THE TONGUE OF THE OCEAN, BAHAMAS.

JOINT PROGRAM OF USGS AND WHOI FOR CONTINENTAL SHELF AND SLOPE

Kenneth O. Emery

By the end of 1963 the first year and a half of the joint WHOI-USGS program for study of the geological history of the Atlantic continental shelf and slope had been completed. The organization has been nearly completely staffed with five scientists from WHOI and seven from USGS. About the middle of the year the group moved from temporary quarters into ones renovated for this work, leading to more efficient work. In addition, R/V GOSNOLD was made ready for sea with the installation of special equipment for the program. Field work aboard ship was carried out during 16 cruises totalling about 103 ship-days. Each staff member participated, to the extent of between 22 and 67 days. Six cruises were for only one day in order to test equipment. The longest cruise was for 28 days.

Field work consisted of two principal objectives. In the first of these, nearly 400 bottom samples were obtained on a 10-mile grid between Nova Scotia and Delaware Bay. These are supplemented by an approximately equal number of samples taken earlier in the Gulf of Maine by the Woods Hole Laboratory of the U.S.Bureau Commercial Fisheries. At each station a photograph of the bottom was made an instant before the sampler closed at the same spot. Other pertinent measurements included temperature, color, and transparency of the water at most stations, and large plankton hauls at some of them. After removal of a portion of each sample for sediment analyses and for living and dead foraminifera the remainder was screened aboard ship to separate benthic animals (which are being investigated ashore by BCF in a cooperative study). The second objective of the field work was the making of continuous seismic profiles in the Gulf of Maine and off Florida and Georgia. As expected, this early sparker work was interrupted by electronic difficulties; nevertheless, some excellent records were obtained. They reveal a general up-building and prograding of the shelf by post-glacial sediments, but in some areas these deposits are so thin that underlying Cenozoic and possibly Cretaceous strata crop out at the shelf-break.

In the laboratory, once equipment was installed and calibrated, analyses were made of many characteristics of the earlier samples from BCF and of the new ones obtained in the present program. Additional previous data include soundings by U.S.Coast and Geodetic Survey and by the Canadian Hydrographic Service; these were compiled into topographic charts of the entire Atlantic con-

tinental shelf, slope, and rise of the United States. The results of the studies of samples and soundings will be summarized by those responsible for particular parts of the work.

Seminar:

Spring, Seminar on General Oceanography. Finished by six of the group, with credit being awarded by Massachusetts Institute of Technology to those who may later take an advanced degree there.

The following talks were given:

25 March, Houston, Texas, Annual Meeting of American Association of Petroleum Geologists -- "The Development of Continental Shelves and Slopes".

19 June, Kiel, Germany, Department of Geology, University of Kiel -- "Marine Geology of the United States".

22 June, Frankfurt, Germany, Sixth World Petroleum Congress -- "Oceanographic Factors in the Origin and Accumulation of Petroleum".

24 June, Bonn, Germany, Department of Geology, University of Bonn -- "Sedimentation in California Basins".

1 August, Woods Hole, Marine Biological Laboratory -- "Continental Shelf Program".

24 August, Tilton, N.H., Gordon Research Conference -- "Oceanographic Factors in Origin of Petroleum".

30 September, Bedford, Mass., Cambridge Research Center -- "Origin of Continental Shelves".

4 November, New York, N.Y., New York Academy of Sciences -- "Oceanographic Factors in Origin of Petroleum".

18 November, New York, N.Y., Annual Meeting of Geological Society of America -- "Marine Geology of the Gulf of Maine".

4 December, Marine Laboratory, University of Georgia, Sapelo Island, Georgia -- "WHOI-USGS Program for Atlantic Continental Shelf and Slope".

7 December, Marine Laboratory, Duke University, Beaufort, N.C. -- "WHOI-USGS Program for Atlantic Continental Shelf and Slope".

12 December, Washington, D.C., Society of Exploration of Atlantic Shelf -- "WHOI-USGS Program for Atlantic Continental Shelf and Slope".

During 1963 the following were published:

Summers, H.J. and K.O.Emery, 1963. Internal waves of tidal period off southern California. J.Geophys.Res. 68:827-839.

Emery, K.O., 1963. Oceanographic factors in accumulation of petroleum. Sixth World Petroleum Congress, Frankfurt, Sec.I, Paper 42, PD2: 1-7.

Emery, K.O., 1963. Coral reefs off Veracruz, Mexico. Geofisica Internacional. 3(1): 11-17.

Rittenberg, S.C., K.O.Emery, J.Hulsemann, E.T.Degens, R.C.Fay, J.H.Reuter, J.R.Grady, S.H.Richardson, and E.E.Bray, 1963. Biogeochemistry of sediments in experimental Mohole. J.Sed.Petrol. 33:140-172.

Kaplan, I.C., K.O.Emery and S.C.Rittenberg, 1963. The distribution and isotopic abundance of sulphur in recent marine sediments off southern California. Geochimica et Cosmochimica Acta, 27:297-331.

Emery, K O. and J.Hulsemann, 1963. Submarine canyons of southern California. Pt.I, Topography, water, and sediments. Allan Hancock Pacific Expeditions, 27(1):1-80.

Emery, K.O. and H.Niino, 1963. Sediments of the Gulf of Thailand and adjacent continental shelf. Bull.Geol.Soc.Amer.,74:541-554.

Degens, E.T., K.O.Emery and J.H.Reuter, 1963. Organic materials in recent sediments: Part III: Biochemical compounds in San Diego Trough, California. N.Jb.Geol.Paleont.,Mh.,5:231-248.

Emery, K.O. and J.S.Schlee, 1963. The Atlantic continental shelf and slope, a program for study. U.S.Geol.Survey Circular 481:1-11.

Emery, K.O., 1963. An aerial study of Hawaiian wave patterns. Pac.Sci.,17:255-260.

Emery, K.O., 1963. Organic transportation of marine sediments: in The Sea, Ideas and Observations on Progress in the Study of the Seas (M.N.Hill, editor), 3:776-793.

Emery, K.O. and C.J.George, 1963. The shores of Lebanon. The Amer.Univ.Beirut, Misc.Pap.in the Natural Sciences, No.1: 1-10 (WHOI 1312).

Uchupi, E. and K.O.Emery, 1963. The continental slope between San Francisco, California and Cedros Island, Mexico. Deep-Sea Research, 10:397-447.

Several papers were prepared and submitted for publication:

Emery, K.O., P.A.Saltman and C.Stitt. Amino acids in basin sediments. J.Sed.Petrol.

Hand, B.M. and K.O.Emery. Turbidites and topography of north end of San Diego Trough, California. J.Geology.

Emery, K.O. and J.Hulsemann. Shortening of sediment cores collected in open barrel gravity corers. Sedimentology. (WHOI 1362).

Emery, K.O. The characteristics of continental shelves and slopes. Amer.Assoc.Petrol.Geologists. (WHOI 1363).

Emery, K.O. Turbidites--Precambrian to Recent. Hidaka Volume (Japan). (WHOI 1423).

TOPOGRAPHY OF THE DEEP SEA FLOOR

Richard M. Pratt

Much of my work this past year was directed toward compiling and analyzing deep-sea topographic data in conjunction with the East Coast Continental Shelf study. Sediments which cross the shelf are traceable to the limits of the abyssal plains, therefore the topographic analysis was extended to a logical limit at the end of the abyssal plains. The Newfoundland Rise and Puerto Rico Trench are the logical northern and southern limits of the study area. Topographic data for this region of the deep sea were assembled in the form of a chart having contours mostly at a 50-meter interval. A companion

chart illustrates the distribution pattern of the chief kinds of sediments.

The major topographic features, or provinces beyond the continental slope, off the East Coast are (1) the Sohm (2) Hatteras (3) Nares Abyssal Plains (4) the Blake-Bahama Basin (5) the Blake-Bahama Platform and (6) the Bermuda Rise. The submarine canyons on the continental slope, the continental rise, and the abyssal plains form a graded profile. Their gradient and areal extent seem to be dependent on the distribution and transportation of terrigenous sediment upon them. Recently accumulated data on deep-sea cores give good evidence that the silt and sand covering the plains are displaced continental sediment in an essentially quartz-free oceanic environment.

The fill of terrigenous sediment extends all the way to the southern arm of the Sohm Abyssal Plain between Bermuda and the Mid-Atlantic Ridge. Here the plains are very flat and consist of terrigenous clay and silt. The Nares Abyssal Plain receives sediment through Vema Gap from the Hatteras Abyssal Plain, which in turn has received most of its sediment through the canyons cutting the slope south of New York and New England. Nares Abyssal Plain is only partially developed and is actually perched above depressions in Nares Deep proper farther seaward.

Pleistocene glaciation was a major factor in developing sediment dispersal patterns as well as topography in the northern part of the region. Besides the direct distribution of sediment into the ocean by ice rafting and glacial outwash, eustatically lowered sea levels resulted in accelerated erosion and the distribution of sediment directly into the ocean basins.

The Blake Plateau and Bahama Banks form a carbonate province characterized by very thick accumulations of limestone and recent calcareous sediment. Accretion of the carbonate deposits into steep-sided banks and limited distribution into the adjacent deep-sea basins resulted in abrupt boundary escarpments with marginal deeps. Sediment transported seaward by the Gulf Stream has accumulated on the Blake Outer Ridge which juts into the Hatteras Abyssal Plain and essentially cuts off the Blake-Bahama Basin. Similarly Bermuda appears to have been a source of high carbonate sediments since the Cretaceous Period and some of the irregular swells and depressions on the Bermuda Rise may be largely sedimentary in origin.

During the year 1963 the following were published:

Pratt, R.M., 1963. Great Meteor Seamount. Deep-Sea Research, 10:17-25.

Pratt, R.M., 1963. Bottom currents on the Blake Plateau. Deep-Sea Research, 10:245-249.

Pratt, R.M., 1963. Photographie auf dem Meeresgrund. Kosmos, 59:306-311.

TOPOGRAPHY OF THE SHELF AND SLOPE

Elazar Uchupi

A set of three topographic charts of the continental margin off the east coast of the United States at a scale of 1/1,000,000 has been compiled. These charts are based mainly on soundings of about 300 smooth sheets from the Coast and Geodetic Survey and the Canadian Hydrographic Service plus soundings from Woods Hole Oceanographic Institution. The northern sheet extends from the Bay of Fundy to Delaware Bay, the central one from Delaware Bay to Cape Fear, and the southern chart from Cape Fear to Key West. A 20-meter interval was used to a depth of 200 meters, and a 200-meter interval beyond that depth.

The following physiographic provinces can be recognized in this region: (1) The Nova Scotia Continental Shelf. The irregular surface of the shelf in this area contains a series of basins about 200 meters deep separated by flat-topped banks. Depth at the shelf-break is about 140 meters, sediments range from green silt in the basins to sand and gravel on the banks. (2) The Bay of Fundy, a shallow trough between Nova Scotia and New Brunswick. Sparker records indicate that the B y is a gently-dipping syncline composed of Triassic sediments. (3) The Gulf of Maine, a rectangular depression atop the shelf, is flanked on its seaward side by Georges Bank and is connected to the open ocean by way of Northeast and Great South Channels. At least 23 basins that range in depth from 80 to 380 meters and are separated by low swells and banks, are present in the Gulf. Sediments range from brown silt in the basins to sand and gravel atop the banks. Continuous seismic profiles indicate that the Mesozoic to Recent sediments atop the Paleozoic basement complex average less than 200 meters thick. (4) Georges Bank, an immense barrier at the entrance of the Gulf of Maine. On the crest of the bank are many large northwest-southeast trending sand ridges that are aligned in the direction of the flood and ebb tidal currents. Atop these

ridges are smaller undulations known as sand waves that stream at right angles to the trend of the ridges. Sand is the most abundant sediment on the bank, although scattered patches of gravel are also present. Sparker profiles indicate that the bank is underlain by a thick sequence of Mesozoic-Cenozoic sediments that dip gently in a seaward direction. (5) Nantucket Shoals, which consists of a series of northeast-southwest trending sand ridges similar to those on Georges Bank. (6) The Continental Shelf from Massachusetts to Miami, which ranges in width from about 100 kilometers off Massachusetts to less than 20 kilometers off Miami, Florida (the shelf-break also decreases in depth from about 120 meters off New England to 50 meters off Miami). Atop the shelf are many swells about 20 meters high that trend east-west in the area between Massachusetts and Hudson Canyon and northeast-southwest south of Hudson Canyon. Previous studies indicate that sediments on the shelf consist of relict glacial debris from Massachusetts to Hudson Canyon, relict fluvial and paralic sediments from Hudson Canyon to Cape Hatteras and calcareous organic sediments south of Cape Hatteras. Present day detrital sediments are restricted to a narrow zone near shore, and to the outer edge of the shelf off Block Island. Continuous seismic profiles indicate that the continental shelf off Block Island is of the upbuilding type and that off Martha's Vineyard is of the upbuilding-outbuilding type. (7) Continental Slope, with an average gradient of 3 degrees, and a relief that decreases from 2000 meters off Nova Scotia to 500 meters off Miami. From Nova Scotia to Cape Hatteras the slope is cut by numerous jagged and steep-walled submarine canyons but south of Hatteras the slope is smooth and submarine canyons appear to be absent. Slope sediments north of Hatteras range from sand and gravel in the canyon axes to silt and clay on the rest of the slope. South of Hatteras the scarp is blanketed by glauconic sediments and pelagic calcareous oozes.

During 1963 the following papers were published:

Uchupi, E., 1963. Sediments of the continental margin off Eastern United States. U.S.Geol.Survey Prof.Paper 475-C:132-137.

Uchupi, E. and K.O.Emery, 1963. Continental slope from Cedros Island, Mexico to San Francisco, California. Deep-Sea Research, 10:397-447.

Uchupi, E. and R.Gaal, 1963. Sediments of the Palos Verdes shelf. In Essays in Marine Geology in Honor of K.O.Emery, Univ. S.Calif.Press: 171-189.

The following paper was prepared for publication:

Schlee, J., E.Uchupi and J.Trumbull. Beach and dune sands from Cape Cod, Mass.

TEXTURE OF SEDIMENTS[1]

John S. Schlee

During the year calibration of a modified Woods Hole Rapid Sediment Analyzer was completed, 295 samples from the northern part of the Atlantic Continental Shelf were analyzed for grain size distribution, and a computer program was improved.

Calibration of the sediment analyzer brought out several significant observations. The settling time of different size particles in sediment mixtures follows the general slope of the values computed by Stokes' Law and the Impact Formula, but the curve is shifted toward a faster settling time; the shift results in settling-time values that are 1/2 to 2/3 of those given by fall of single spherical particles (fig. 1). Variation of sample size (5- to 10-gram sample) appears to have little effect on settling time. To a limited extent, the nature of the size distribution affects the fall time of size classes within the distribution. Where a given size grade occurs alone, as in well-sorted sand, or where this grade is the finest fraction of a less well-sorted sediment, its settling time can be 1.3 to 2.0 times as long as the settling time of the same grade within several size classes of a less well-sorted sediment.

Of the 295 size analyses for bottom sediments, only 47% showed a log-normal distribution (fig. 2). This log-normal type is best shown in sediment where the range of grain sizes is limited and perhaps, where the sediment was deposited by only one agent at one time. A polymodal distribution is common where the range of grain size is broad and in samples containing gravel that has not yet been analyzed.

The computer program has been modified to improve the calculation of statistical parameters from size analyses. A three-point Lagrangian interpolation, applied to data by personnel at WHOI computer center, fits a series of second-order

[1]Publication authorized by the Director, U.S.Geological Survey.

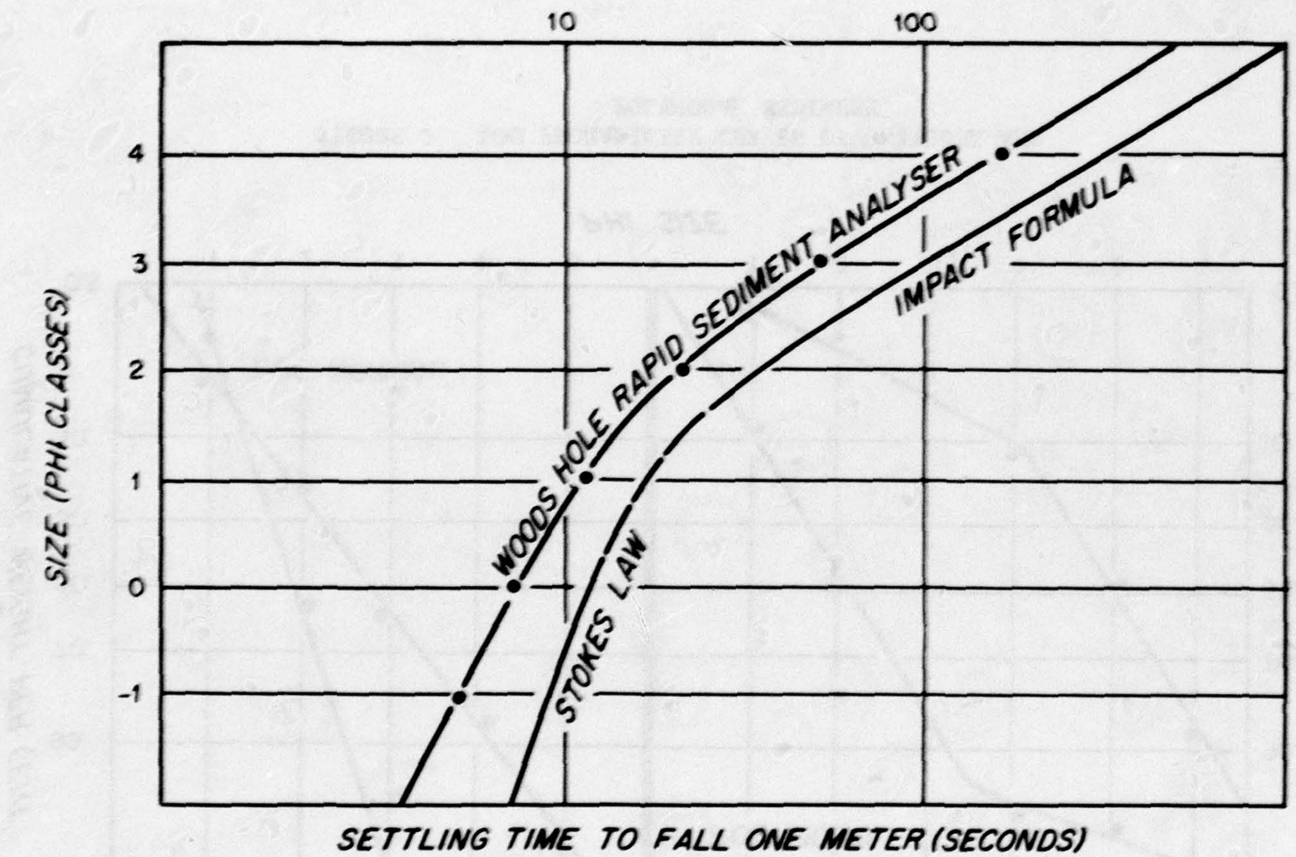


FIGURE 1. COMPARISON OF SETTLING TIME CURVE FROM WOODS HOLE SETTLING TUBE AND STOKES LAW - IMPACT FORMULA.

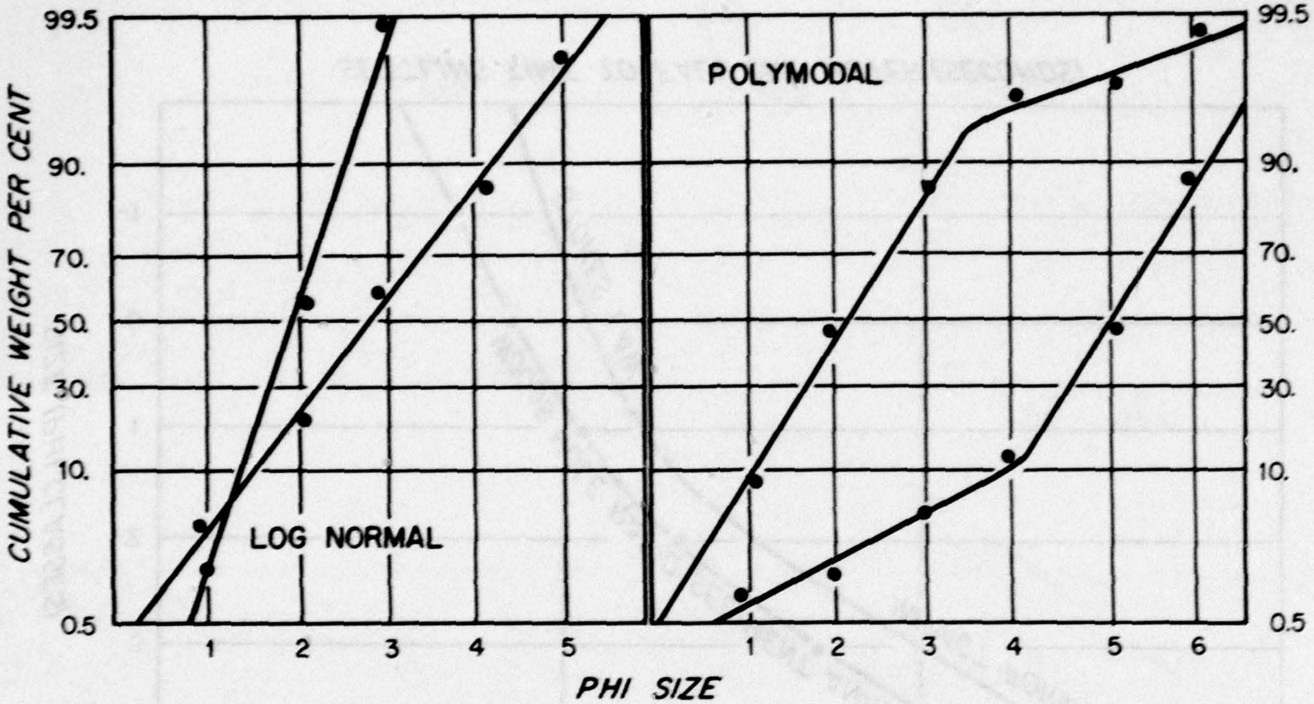


FIGURE 2. LOG PROBABILITY CURVES OF UNIMODAL AND POLYMODAL SEDIMENT.

curves (parabolas) to the data points so that intervening points can be generated to approximate the curve of a continuous size-frequency distribution, rather than the chords of a size-frequency polygon. In addition, the computer program calculates primary and secondary modes and sediment type.

Publications:

Emery, K.O. and J.S.Schlee, 1963. The Atlantic Continental Shelf and Slope, a program for study. U.S.Geol.Survey, Cir. 481, 11 pp.

Schlee, John S. 1963. Sandstone pipes of the Laguna area, New Mexico. J.Sed.Pet. 33: 112-123.

Schlee, John S. 1963. Early Pennsylvanian currents in the southern Appalachian Mountains. Bull.Geol.Soc. America, 74: 1439-1452.

GRAIN SIZE DISTRIBUTION OF SHELF SEDIMENT[1]

Donald J. Casey

During 1963 more than 300 sediment samples of the New England continental shelf were analyzed for grain size distribution. Triangular diagrams showing the percentages of sand, silt, and clay illustrate three distinct associations. Gravel was present in some of the samples but was omitted from the analyses.

Non-gravel fractions of samples from glacial areas such as the Gulf of Maine (figure 1) show a large variation of sediment types, ranging from detritus composed of 85% sand, 10% silt, and 5% clay, to sediment containing equal amounts of silt and clay, with no sand. A general relation exists between the depth of water in which the sample was collected and its size distribution; samples composed entirely of silt and clay are from the basin areas, and those having large percentages of sand are from shallower areas.

Sediments from Georges Bank (figure 2) and from the area south of Nantucket (figure 3) are dominantly sand. Sand in the

[1]Publication authorized by the Director, U.S.Geological Survey.

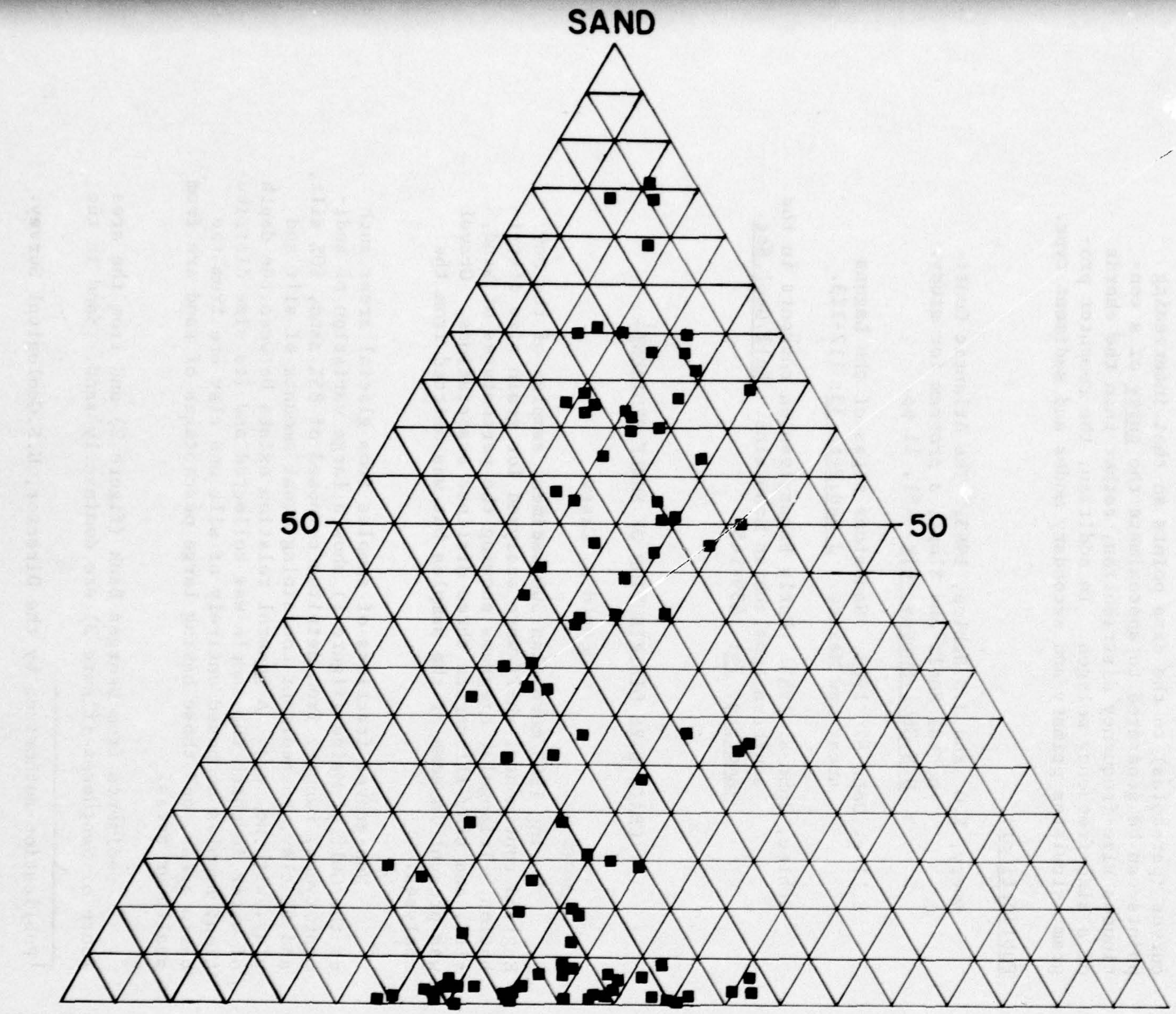


FIGURE 1. TRIANGULAR DIAGRAM OF SEDIMENT SAMPLES FROM THE GULF OF MAINE

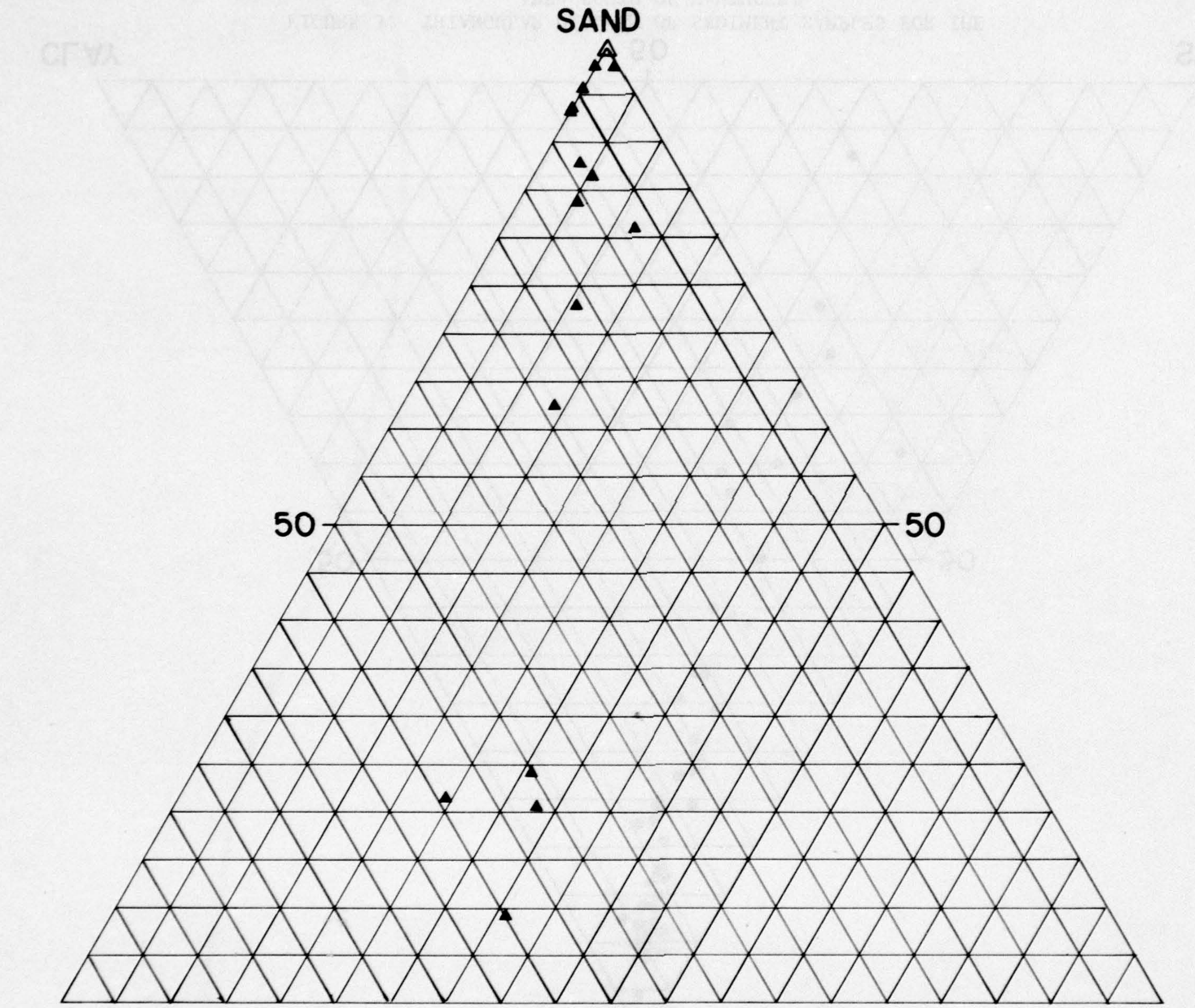


FIGURE 2. TRIANGULAR DIAGRAM OF SEDIMENT SAMPLES FROM GEORGES BANK

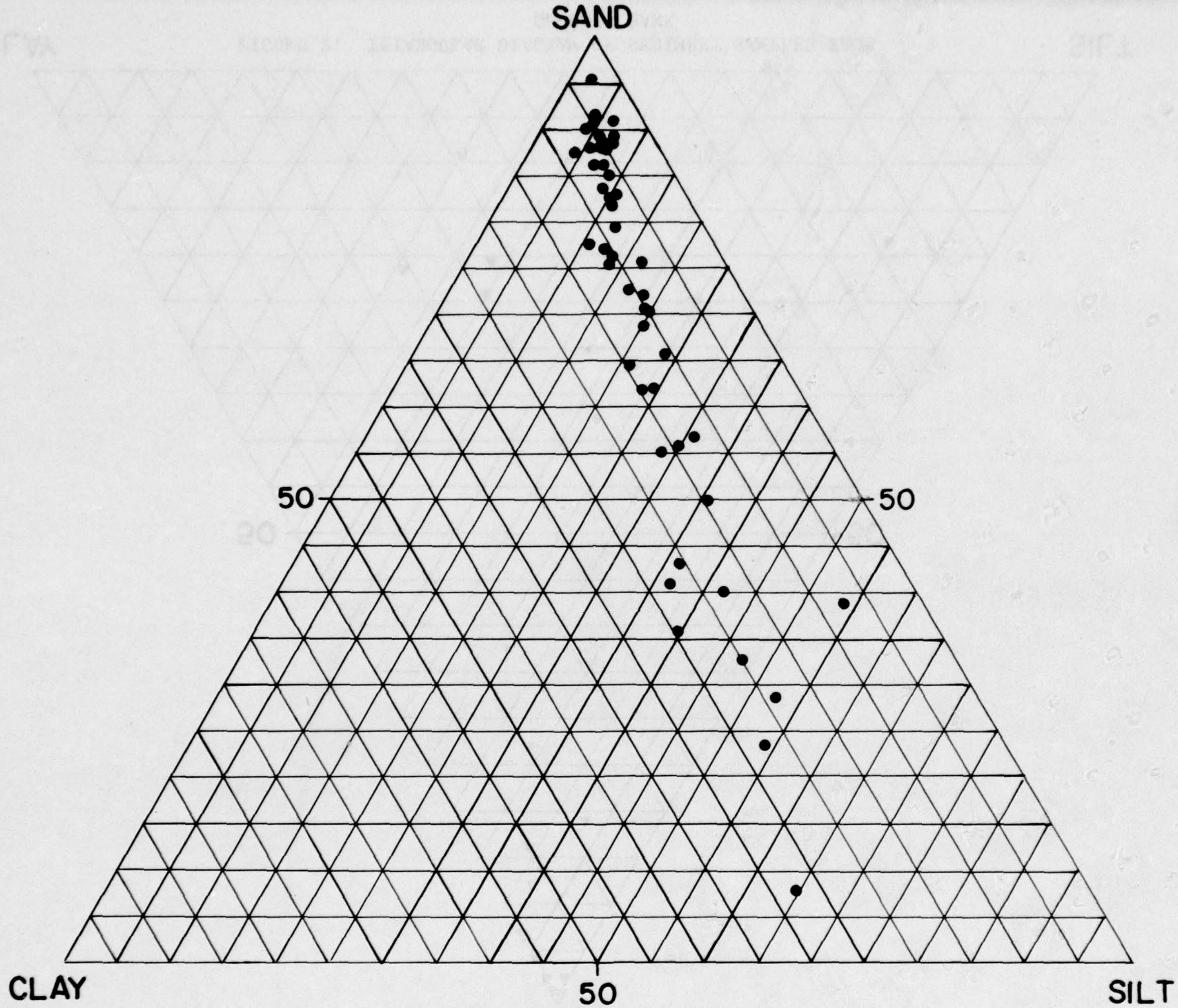


FIGURE 3. TRIANGULAR DIAGRAM OF SEDIMENT SAMPLES FOR THE AREA SOUTH OF NANTUCKET

latter area is associated consistently with a small amount of clay, but the amount of silt varies. Except for the outer part of the shelf, the amount of silt becomes more abundant with increasing distance from shore.

GROSS SAND-FRACTION MINERALOGY AND GRAIN CHARACTERISTICS OF BOTTOM SAMPLES NOVA SCOTIA TO CAPE MAY[1]

James V.A. Trumbull

Bottom samples collected at ten-mile intervals in a rectangular grid covering the continental shelf and part of the continental slope between Nova Scotia and Cape May (N.J.) have been examined microscopically to determine the texture and gross composition of the sand-size fraction (1/16 mm to 2 mm). The samples total 785, of which 369 were collected during 1963 from R/V GOSNOLD of the Woods Hole Oceanographic Institution, and 416 were collected in previous years by the U.S.Bureau of Commercial Fisheries.

A pilot plot of results for 200 samples from the northern Gulf of Maine and from the shelf south of Martha's Vineyard was made. Over the broad central part of the shelf south of Martha's Vineyard the percentages of rock fragments, dark minerals, and shell fragments are very low (one percent or less), indicating low-energy conditions of deposition, and the percentages rise both near the land and seaward near the shelf break. Conversely, 3 percent of mica and 2 to 3 percent of glauconite are present on the middle part of the shelf, but percentages decrease toward the higher-energy areas landward and seaward. Presumably the higher-energy nature of the sediments of the outermost part of the shelf is due to the presence of a shoreline resulting from a lower sea level during Pleistocene time.

Most of the shelf sediments south of Martha's Vineyard have an admixture of highly rounded and strongly frosted quartz grains that average about 0.5 mm in diameter. These large grains contrast with poorly rounded, nonfrosted, and much smaller (less than 0.25 mm) quartz and feldspar grains in the same samples. Many samples are strongly bimodal in particle-size distribution

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1 Publication authorized by the Director, U.S.Geological Survey.

because of the presence of the large round grains. The large grains may be due to transport by strong Pleistocene winds from land areas to the north, and perhaps in part to aeolian action on the shelf sands themselves during stages of lowered sea level. The conditions of their origin must have been markedly different from those of the finer-grained marine sediments with which they now occur and which were deposited more recently. Similar large rounded and frosted quartz grains are found over much of Georges Bank to the east.

In the northern Gulf of Maine the character of the sand fraction seems little dependent upon distance from shore or upon absolute depth of water. Occurrence of the two distinct types of sediment is controlled instead by whether the sample is from a topographically low flat-bottomed area of quiet present-day deposition, or from a topographically high or irregular area being swept clear of present-day fine-grained sediments. In the higher areas sediments are poorly sorted and contain numerous angular rock fragments; they seem clearly to be of glacial origin. The lower areas of present-day deposition contain almost no rock fragments or particles in the sand and gravel size range, and they have high percentages of mica and foraminifera.

The only component of the Gulf of Maine sands that appears to be dependent on distance from land is glauconite. Near the middle of the Gulf concentrations of as much as 2 percent are present, but little or none is found near land.

The standard sample spacing of about ten miles is adequate to portray clearly the gradients of compositional and textural change in the shelf sediments south of Martha's Vineyard. In the northern Gulf of Maine that spacing is too great to portray the gradients. Because of the abrupt and closely-spaced changes in the topography, a spacing of only a small fraction of a mile over most of the entire Gulf would be necessary to define individual areas of sediment types.

MINERALOGY OF SEDIMENTS FROM THE NEW ENGLAND CONTINENTAL SHELF[1]

John C. Hathaway and A. Richard Tagg

The objective of our studies for the year has been to determine the mineralogy of bottom sediments from the northern part of the Atlantic Continental Shelf. Samples are from the continental shelf south of Nova Scotia to the region south of Block Island excluding the Bay of Fundy, the area just north and east of the tip of Cape Cod, and Nantucket Shoals. At least 2 samples per 30'-quadrangle were selected for studies of the distribution of the principal minerals and a wider spacing was used for determination of clay mineralogy. X-ray diffraction was the principal method used to determine the mineralogy as it permits observation of the gross mineral composition of the entire fraction of the sample finer than 2 mm in a single run; material coarser than 2 mm was removed for separate study. Clay mineral determinations required additional runs of the less than 2 μ fraction.

The principal minerals are quartz, plagioclase feldspars, potassium feldspars, mica, chlorite, mixed-layered mica montmorillonite, calcite, amphibole (probably hornblende) and kaolinite. Estimates of the quantities of these minerals were plotted on maps of the area and contoured. The resulting maps show a strong topographic control over the mineralogy primarily through the mechanism of size sorting, although influence of source of sediment can also be seen. The gross mineralogy of the surficial material sampled is affected little or not at all by diagenetic changes. Ratios of the various clay minerals to one another are constant throughout the area and are essentially the same for samples with large and small percentages of total clay.

The mineralogic feature that most faithfully reflects topography is the content of total chlorite and mica. High concentrations follow topographic lows whereas low concentrations occur on the topographic highs. This distribution was expected because of the concentration of fine material in the lows and the winnowing of such material from highs. The quartz content reflects topography to some extent but is modified by variable amounts of feldspar in the silt and sand fractions. Georges Bank, for example, is a topographic high having high quartz content, very low feldspar, and very low chlorite and mica content. The area of Jeffrey's Ledge, however, is a topographic high having

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[1] Publication authorized by the Director, U.S.Geological Survey.

a moderate quartz content, relatively high feldspar, and low chlorite and mica. The relatively high feldspar content may reflect a strong contribution of glacial material. The very low feldspar content of Georges Bank may result from either minor contribution of glacial material or loss of feldspar by subaerial erosion during intervals of lowered sea levels or by surf action during postglacial transgression of the sea. Plagioclase feldspars are much more abundant than potassium feldspars throughout the area. The type of feldspar is independent of the topography.

Fine textured surface features of sand grains from various mineralogic and topographic zones of the shelf observable by electron microscopic techniques may reveal the erosional history of the grains. Such studies have been started but as yet have been limited to the development of reliable sample preparation techniques.

The minor minerals in the sediments are also under study; heavy minerals in the sand sizes as well as minor clay minerals in the finer sizes are being determined. Insufficient data preclude the drawing of any conclusions at present.

Seminar:

John C. Hathaway conducted a seminar in Principles of X-ray Diffraction during the late spring and summer. It was completed by 7 persons including one from the Bureau of Commercial Fisheries.

Publication:

Carroll, D. and J.C.Hathaway, 1963. Mineralogy of selected soils from Guam. U.S.Geol.Survey Prof.Paper 403-F, 53 pp.

ORGANIC CONSTITUENTS

Jobst Hulsemann

Most of the report time (some 60% of the year 1963) was spent with laboratory work including instruction and training of technicians. The total number of analyses carried out is: 1034 for calcium carbonate, 1399 for Kjeldahl-nitrogen, and 1771 for total and organic carbon. These figures include "blank"- and "standard-reagent-" analyses.

To facilitate computations involved in the large number of analyses, the WHOI electronic computer was used. With the aid of Mr. Duncan Morrill (head of the WHOI computer center) a computer program was written. A description of our method for the analysis of carbonate in sediments and computer processing has been prepared for publication. Manuscripts for the machine handling of the other routine analyses (nitrogen and carbon) are in preparation.

The samples so far obtained cover most of the northern part of the continental shelf from the Bay of Fundy and Nova Scotia to New York. The results are plotted and contoured in chart form and show that the calcium carbonate content is very low and rather uniform. More than 80% of all samples contain less than 5% $CaCO_3$ however in three localities, the calcium carbonate increases to more than 30%. At two locales (entrance to Bay of Fundy and southwest of Nova Scotia) high carbonate values are due to shell debris of pelecypods and other mollusks, and perhaps reflect accumulation at the time of lower sea level during the Pleistocene. At the third locality (slopes between Browns and Georges Bank) the sediment contains a great many foraminiferans whose tests are responsible for the carbonate content. We may expect similar results deeper on the continental slope beyond the presently sampled area.

The results of the analyses for organic carbon and nitrogen reveal a different relationship. Here the contours of equal contents of carbon and nitrogen reflect the irregular topography of the area. Higher concentrations of organic matter occur in the basins and low values on the banks. It appears that organic carbon is even a little more sensitive to topography than is aminoid nitrogen. Noteworthy are two belts of higher concentrations of organic matter. One lies within 50 km of shore and the other is about 150 km off the coast. It is suspected that the two belts reflect different sources of the organic matter (land-derived near shore; marine farther off shore), and this hypothesis will be tested. Typical values within basins and depressions in the Gulf of Maine are: 1.8% organic carbon and 0.25% Kjeldahl nitrogen, and on banks 0.2% organic carbon and 0.01% Kjeldahl nitrogen by dry weight.

A lecture tour was undertaken as Visiting Scientist of the American Geological Institute from 17 to 23 February to Dickinson College, Carlisle, Pa., and Allegheny College, Meadville, Pa. Seminars on marine geology were held and the following talks were given:

The Sedimentary Environment of Marine Basins

The Sedimentary Environment of Submarine Canyons

Geological Investigation of the Experimental Mohole 1961.

In addition a talk was presented on 15 July before the Journal Club, Woods Hole Oceanographic Institution: Some Characteristics of Experimental Mohole Sediments.

Papers prepared and submitted for publication:

Emery, K.O. and J.Hulsemann. Shortening of sediment cores collected in open barrel gravity corers. Sedimentology. (WHOI No.1362).

Papers published:

Rittenberg, S.C., K.O.Emery, J.Hulsemann, E T.Degens, R.C.Fay, J.H.Reuter, J.R.Grady, S.H.Richardson and E.E.Bray, 1963. Biogeochemistry of sediments in experimental Mohole. J.Sed.Petrol. 33: 140-172.

Emery, K.O. and J Hulsemann, 1963. Submarine canyons of Southern California: Pt.I Topography, water, and sediments. Allan Hancock Pacific Expeditions, 27, pt.I: 1-80.

FORAMINIFERA[1]

Thomas G. Gibson

Approximately 500 surface samples from the Atlantic Shelf between the southern coast of Nova Scotia and the eastern end of Long Island have been processed. The samples have been weighed and the number of Foraminifera counted, then calculated as number of specimens per gram of sediment. When plotted on a base map, these data show several interesting patterns. The lowest number of specimens is found in the nearshore waters all along the coast and in the shallow parts of Georges Bank. Because the nearshore sediments range from mud off New Hampshire and Maine to coarse sand off Cape Cod and southward, probably something other than sediment type or rate of deposition is the controlling factor. Less than one specimen per gram occurs in most of the nearshore waters, in striking contrast to large numbers found at similar depths off Florida and in Long Island Sound. Generally, as the

[1]Publication authorized by the Director, U.S.Geological Survey.

distance from shore increases, the abundance of specimens also increases. A high of 13,000 specimens per gram is found at a depth of about 200 meters in the area south of Georges Bank. The progressive increase in abundance relative to distance from shore exists only in the area south of the Gulf of Maine. Very heterogeneous patterns are found in the Gulf of Maine because of the irregular topography.

The ratios of planktonic to benthonic Foraminifera have also been plotted. Generally, the ratio of planktonic to benthonic specimens increases with distance from the shore. For this parameter the Gulf of Maine again exhibits a heterogeneous pattern, which is generally related to the topography. Both the benthonic and planktonic faunas show a striking change at the northern edge of Georges Bank. North of this area, the fauna consists mainly of arctic to subarctic species, whereas farther south temperate to subtropical species predominate. This change is sudden and marked. Although the benthonic faunas do not overlap, a few warm-water planktonic specimens are found in the Gulf of Maine, probably due to the incursion of small masses of Gulf Stream waters. Of the few species that are common to both areas, the specimens in the Gulf of Maine are only one-quarter to one-third as large as those found south of Georges Bank; this is an interesting example of possible phenotypic variation.

In both faunal provinces, marked zonation of species with depth is exhibited. A fairly sharp break in faunal composition occurs at approximately 40 meters, and a major break occurs at 90 to 100 meters. Although the fauna is composed of 30 to 50 species in depths of less than 100 meters, usually one or two species dominate at greater depths.

BENTHIC BIOLOGY

Arthur S. Merrill

During the year 1963, a total of 387 samples were collected with a Campbell grab sampler aboard the WHOI R/V GOSNOLD at predetermined stations. The samples were received at the BCF Laboratory for sorting, identifying, counting, and weighing the macrofaunal components. The stations complement a series of 389 stations taken earlier by this laboratory and they complete this program of bottom sampling from the Bay of Fundy south along the continental shelf to Cape May, New Jersey, on a 10-mile grid, leaving only the deep water slope stations yet to be finished.

At the beginning of 1963 there remained about 200 earlier BCF samples to sort and analyze. This work was completed in August and sorting of the GOSNOLD material began immediately. At the end of the year 129 GOSNOLD samples had been processed. It is hoped that the remaining GOSNOLD material will be completely worked up by late spring.

Photographs, taken an instant before a grab is made, are being analyzed along with the animals actually taken at stations in order to approximate the usefulness of this tool. A report will be issued soon on this technique.

Personnel at this laboratory participated in two GOSNOLD cruises. This resulted in a better understanding between the geologists and biologists of the kind of problems which each are investigating.

ELECTRONICS

Russell K. Paul

Activities since my arrival in March, 1963, fall into five catagories: instruction; setting up shop; assembling and maintaining a seismic profiling system; design and construction of equipment; and participation in cruises.

Several trips were made to the Westrex Company in New York City to be instructed in the operation and maintenance of the Precision Depth Recorder, and one trip to the Lamont Geological Observatory for additional information about the PDR. Three weeks during the spring were spent with Del Electronics Corporation at Mt.Vernon, New York, during final assembly and test of the 10,500-Joule sparker. In November a one-week seminar was attended at the Alden Electronic and Impulse Recording Equipment Company in Westboro, Mass., where detailed instruction was received in the operation and maintenance of the Precision Graphic Recorder, or PGR.

An electronics and mechanical shop was assembled, with proper test equipment and tools either purchased or secured from the surplus lists. Present facilities are adequate for most routine maintenance; the facilities of the Institution are available, and have been used, when our own are inadequate.

During the year most of the components of the sparker and receiving systems were received and tested. The sparker was

permanently installed aboard R/V GOSNOLD, as was the PDR. A five-element linear hydrophone array of WHOI design was received from Rayflex Explorations, Inc., and has been used on one major cruise. Other commercially-manufactured components include a programmer, two variable filters, and a ten-channel emitter follower of WHOI design.

Several items of electronic equipment were constructed in our shop, including a five-channel mixer, a monitoring amplifier, and a signal amplifier all of WHOI design. In addition power supplies were designed and constructed for special purposes, namely the hydrophone array, which also required the construction of special cabling and distribution panels. Modifications were made to several items of equipment. Changes were made in the ignition switch unit of the sparker to enable faster and easier switching of energy levels. It became evident that the PDR needed the flexibility of a variety of paper-feed rates to be of maximum use in seismic profiling, and a five-speed transmission was accordingly designed and constructed for installation in the recorder. Excellent results have been experienced with this unit. A function-switching chassis was also designed and wired into the PDR to enable fast selection of either echo sounding with the normal PDR configuration, or seismic profiling, which requires a rather drastic re-deployment of the electronic sub-assemblies.

Three major cruises were undertaken for sparker operation; two of these were a success from the standpoint of equipment operation. The third cruise was not successful due to critical malfunction in both sound source and receiving equipment. In addition, several short cruises were made to test and adjust equipment.

HYDROLOGY AND GEOCHEMISTRY OF THE ATLANTIC COAST AND CONTINENTAL SHELF[1]

Robert H. Meade and Frank T. Manheim

Planning has begun for a program of study that will extend offshore the Geological Survey's traditional interests in the hydrologic cycle. The problems to be studied include: (1) the mixing of fresh and saline waters at river mouths, in large estuaries, and over the open shelf; (2) the fate of the dissolved ions and sediment loads discharged by rivers into brackish and marine waters; and (3) the interstitial waters of the sediments, their composition, migration, and relations to the bulk physical and chemical properties of the sediments.

These studies will get under way in 1964. Among those specifically planned is a series of observations at the mouth of the Connecticut River to assess the mixing rates and processes at a narrow river mouth, the movement and deposition of the sediment load, and the fate of the dissolved constituents contributed by the river. Detailed study of the mixing rates and processes on the open shelf will begin with the May-June cruise of the R/V GOSNOLD, during which the salinity and temperature (and perhaps the turbidity) of the waters between Cape Hatteras and Cape Kennedy will be measured to give some indication of the influence and the eventual fate of the fresh water that discharges from the land. Interstitial water will be squeezed from the sediments that are taken during some of the bottom-sampling cruises of R/V GOSNOLD, and returned to Woods Hole where laboratory facilities will be set up to chemically analyze the sediments and waters. Both major and minor elements will be studied.

<u>Publication during 1963</u>:

Meade, R H., 1963. Factors influencing the pore volume of fine-grained sediments under low-to-moderate overburden loads. <u>Sedimentology</u> (<u>2</u>): 235-242.

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[1]Publication authorized by the Director, U.S.Geological Survey.

APPENDIX

The Problems of QUATERNARY MICROPLANKTON

David Wall

Background Information

Dinoflagellates as microfossils occur in marine, sedimentary rocks ranging from Rhaetic to Recent. In addition to many extinct forms, several of the most common present-day genera, including Gonyaulax and Peridinium are known from the fossil record. Associated with dinoflagellates in these and much older strata are similar microfossils commonly called "hystrichospheres". Until 1963 the latter were allocated taxonomically to the Hystrichosphaeridae, a group of uncertain classificatory standing, but then this system was abandoned in favour of a two-fold division into Dinoflagellata and Acritarcha. A critical review of the morphology of many fossils previously called "hystrichospheres", including that of the important type genus Hystrichosphaera, demanded that they should be classified with the Dinoflagellata, even though there were differences between these and living flagellates. The remaining forms, all of unknown biological affinity, were allocated to a new group, the Acritarcha.

Dinoflagellates are recovered from sedimentary rocks by the same techniques as those developed for the extraction of pollen and spores. Their geological application also lies in the same direction, namely, rock dating, stratal correlation and the determination of ancient environments. At present, fossil microplankton is being studied by palynologists of most petroleum companies and in academic institutions throughout the world.

The programme now being conducted at Woods Hole is an investigation into some problems associated with Recent and Pleistocene microplankton. From the point of view of the micropalaeontologist, very little is known of the presence and nature of dinoflagellate remains in recent sediments. Again, from a biological viewpoint, the marked differences between living dinoflagellate populations and dinoflagellate remains found in muds on the ocean floors require explanation. It is hoped to demonstrate that fossil dinoflagellates can provide the marine geologist with a new method for the correlation of sediment cores and reveal to biologists new aspects of the morphogenesis of dinoflagellates.

The programme was pursued along two lines, one micropalaeontological, the other, biological.

I. Micropalaeontology

A deep-sea sediment core (A 254/330) from the Yucatan Basin of the Caribbean (19°35'N, 84°51'W) has been examined for microplankton. A detailed report of the results of this work has been prepared; the important findings are summarized here.

1. The core was 6 m long and comprised a homogeneous grey lutite from the base to a depth of 34.5 cm, above which there were laminated silty clays of yellowish-olive colour alternating with grey lutite bands.

2. Dinoflagellates were extracted in large numbers from 10 selected samples by treating the clays with dilute HCl, hot HF, Schulze's solution and dilute KOH followed by staining with Safranin O. The specimens were found to be very delicate and were examined therefore in open preparations.

3. Thirty-one species of dinoflagellates were identified or described as new species; of these, 15 were common. Three genera were abundantly represented, Hystrichosphaera (10 species), Hystrichosphaeridium (7 species), Gonyaulax (6 species) and five other genera were recorded (Nematosphaeropsis, Actinotheca, Ascodinium,? Dioxya plus a new genus to be named later).

4. The 10 assemblages obtained were constant in their species content; 15 species were common to all the samples, the remainder were sporadic in occurrence.

5. The frequency distribution of species and genera varied with depth in a regular manner. Possibly the changes observed were due to climatic change and may well provide a suitable basis for correlation of cores as the investigation proceeds. The most significant fluctuation observed involved a marked decrease in the abundance of species of Hystrichosphaera and Hystrichosphaeridium, together with a rapid increase in the relative abundance of Gonyaulax between the depths of 10 and 40 cm in the core.

(The absolute ages of the samples will have to be determined by radiocarbon methods. Comparative data can be obtained by examination of foraminifera from the core.)

6. The present investigation furnishes original information about late Pleistocene and Recent dinoflagellate assemblages. The youngest Tertiary assemblages known are of Miocene age. These are very dif-

ferent in composition, so that between the Miocene and Recent there were obviously extinctions and evolutions of some dinoflagellates. These form a good potential basis for dating older Tertiary and Quaternary strata when longer cores are available for examination.

7. Preparations of calcareous nannoplankton (discoasters and coccoliths) were made and examined. These were not studied in great detail but it was determined that discoasters were present throughout the core.

II. Biology of Microplankton

Biological information concerning hystrichospheres and fossil dinoflagellates was sought by making detailed studies of the morphology of the fossils and by attempting to locate similar bodies in plankton hauls.

1. Morphological observations.

Fossil dinoflagellates have a transverse and longitudinal furrow and plate-areas comparable with those of living armoured dinoflagellates. However, fossil forms, including those from the Caribbean, also possess a dorsal aperture called the archeopyle and are invariably characterized by having long spines or crests upon their surface. Consequently fossil forms cannot be identified with any known living species and the theory currently held to explain this anomaly is that fossil forms are in fact a type of dinoflagellate cyst as opposed to a motile phase.

An important observation from Caribbean fossil forms is that the plate arrangement of species previously classified with the fossil genera Hystrichosphaera and Nematosphaeropsis is compatible with that of Gonyaulax. This adds strength to the idea that hystrichospheres of this type are dinoflagellate cysts. These "cysts" appear to be an intermediate stage in the life cycle of a thecate dinoflagellate between the existence of the motile flagellate stage and the formation of a "spore" inside the theca. The spore is liberated by escape through the archeopyle. The intermediate stage is possibly benthonic, which accounts for its absence in literature dealing with the life cycles of dinoflagellates, although on the other hand it is probably a stage which may be entirely lacking in some cycles. It is hoped to gain more information on this subject by setting up special culture experiments.

2. Examination of Plankton Hauls

Plankton hauls taken on the R/V CHAIN Cruise 37 (July, 1963) between Woods Hole and Bermuda were examined for organisms resembling hystrichospheres or other fossil forms of dinoflagellate. The results of this investigation were largely negative; although large numbers of thecate dinoflagellates were found, only a few specimens comparable with fossil forms were found. This confirms the rarity of such forms in plankton but adds a little to the evidence slowly accumulating that hystrichospheres are not extinct but represent a phase in the life history of certain dinoflagellates.

In addition to examination of plankton hauls, records of previous expeditions were examined for the same purpose. This resulted in interest in forms described as Trochiscia and Pterosperma. Two species correspond to fossil forms, namely, Pterosperma ovum Gaarder 1954 and P. labyrinthus Ostenfeld 1903. Again, this suggests that hystrichospheres can be found alive.

III. Miscellaneous

A catalogue of fossil Dinoflagellata and Acritarcha is being prepared at the Institution.

IV. Conclusions

1. Fossil dinoflagellates and hystrichospheres are abundant in the Caribbean deep-sea Yucatan B sin and initial results indicate that they will serve as a means of correlating sediment cores.

2. Hystrichospheres are not extinct and some possess a close relationship with the present day genus Gonyaulax. Fossil dinoflagellates and hystrichospheres are morphologically distinct from living, planktonic dinoflagellates but may well comprise part of the life cycle of living thecate forms.

GEOPHYSICS

DEPARTMENT OF GEOPHYSICS

J. B. Hersey, Department Chairman

INTRODUCTION

The research program within the Geophysics Department includes problems in physical oceanography, marine biology, and geology as well as those problems commonly regarded as part of geophysics. This combination results from the long-time interest of many members of the department in hydroacoustics and the significance of sound to research in these other disciplines. Hence the separate reports are deliberately grouped in accordance with discipline or problem area as shown in the table of contents.

Several individual scientists confine their active interest to problems within one area of research so that their work can be described in a single article. Others work in cooperation with different combinations of their colleagues and on problems that are diverse as to problem area or geographic location. A hopelessly disjointed account of their work would be presented if each wrote a single article about his work during 1963. Consequently, articles have been prepared to present our scientific progress in the many problems that have been undertaken. The authorship reflects the principal contributors to the research or technical development.

During the past year many months of several individuals' time was occupied in the search for the THRESHER. The effort was so overwhelming that it is quite impossible to give suitable credit to individuals in the brief mention of this work below. Many scientists have sacrificed a large fraction of their time to this cause since early April and their other research has suffered correspondingly. Nevertheless, the experience gained during the THRESHER search and in the subsequent analysis of data has been valuable scientifically as well as being a source of personal satisfaction to the participants. It will be evident from the other contributions below that the remainder of our research was not completely suspended.

HYDROACOUSTICS AND RELATED STUDIES IN PHYSICAL OCEANOGRAPHY AND MARINE BIOLOGY

LONG-RANGE SOUND TRANSMISSION THROUGH THE DEEP SEA

Lincoln Baxter II, R. Brockhurst, D.D. Caulfield,
H.S.L.Graham and E.E.Hays

Studies were continued of records of deep-sea, long-range sound transmission collected over the last few years in the North Atlantic Ocean and the Mediterranean Sea. The records - made by the automatic recording system discussed in our 1962 summary report (WHOI Ref.#63-18) - have provided confirmation of travel time relations reported by Ewing and Worzel (1948), Officer (1958), Arase (1959), and Hale (1961). The illustrations in the above reports are based on Atlantic Ocean conditions which are similar but not identical to those in the Mediterranean. We have prepared graphical records of examples of Atlantic and Mediterranean sound transmission which strikingly illustrate the similarities and the differences between travel time relations of sound transmission paths in the two seas.

Focussing at intervals, in the Atlantic of 35 miles and in the Mediterranean of 20 miles, and the larger angle subtended in the Mediterranean by refracted rays are known from the theoretical discussions of Ewing and Worzel (1948), Officer (1958), and from experiments with explosive charges. But our new method permits nearly continuous observation (with high resolution) of travel time difference as a function of elapsed time. Much more detailed analysis of range and relative intensity can be made than that provided by previous experiments.

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NEAR-SURFACE SOUND TRANSMISSION

David D. Caulfield and Stanley W. Bergstrom

The outstanding question in sound transmission in the sea is the manner in which the changing physical characteristics of the ocean affect sound propagation. Since near-surface sound transmission work has been conducted for many years at the Institution, large amounts of data have accumulated that are applicable to the problem, including sound velocity measurements, temperature structure profiles (WHOI thermistor chain), and surface wave characteristics.

Most of these data are in analog form and consist of series of numbers too long to handle conveniently by ordinary methods. For instance, one set of sound transmission studies resulted in 75,000 measurements of acoustical energy. The past year has been spent in developing digital computing and handling programs for such large amounts of data.

The first problem was to develop means of storing the data from experimental sound transmission runs and computing normalization factors, calibration factors, and automatic data contouring programs.

Figure 1 represents a sample of contoured field data from a sound transmission study in the Norwegian Sea. These contours were computed by the GE 225 Computer and plotted automatically from IBM cards on the Electronics Associates Plotter. The contours are lines of equal energy level.

The next problem was to convert theoretical models of sound transmission into complete digital programs. Figure 2 represents a theoretical ray diagram based on the velocity structure present at the time the acoustic data in Figure 1 were collected. This particular model was based on 80 linear segments representing a continuous velocity profile. One investigation is being made to consider how accurate the velocity profile has to be in the theoretical model.

Procedures have been worked out, although the computer programming is not complete, for computing the energy levels from the ray diagram and ending with a contour plot for direct comparison with the experimental data plots.

By means of the computer the two plots shown (Figs.1 and 2) were completed in one day. It required weeks to construct such figures by older methods and the results were less accurate.

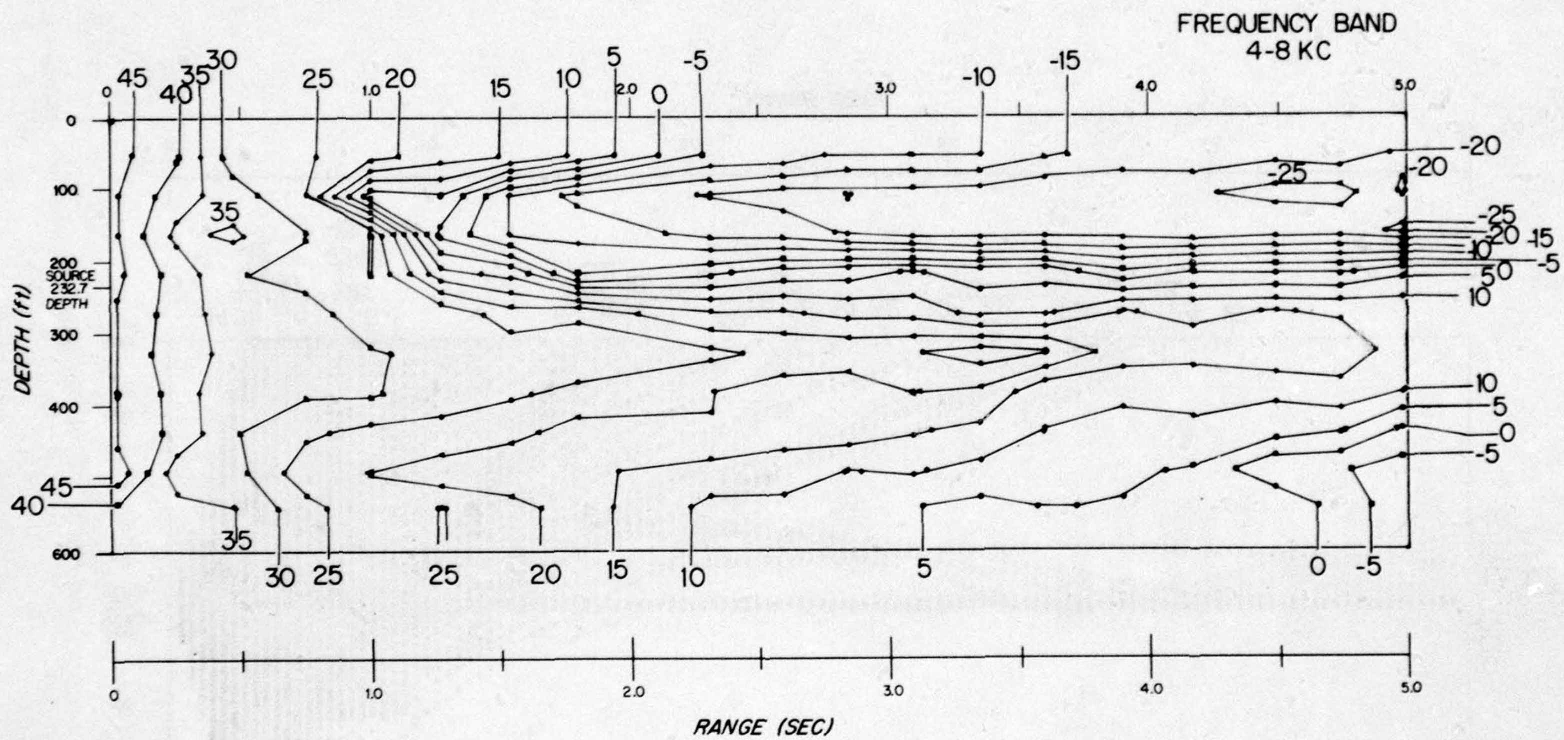

FIGURE 1. ISO-ENERGY FLUX IN 5-DB INTERVALS, RELATIVE TO THE FLUX AT ONE-YARD FOR NORMALIZED FIELD DATA.

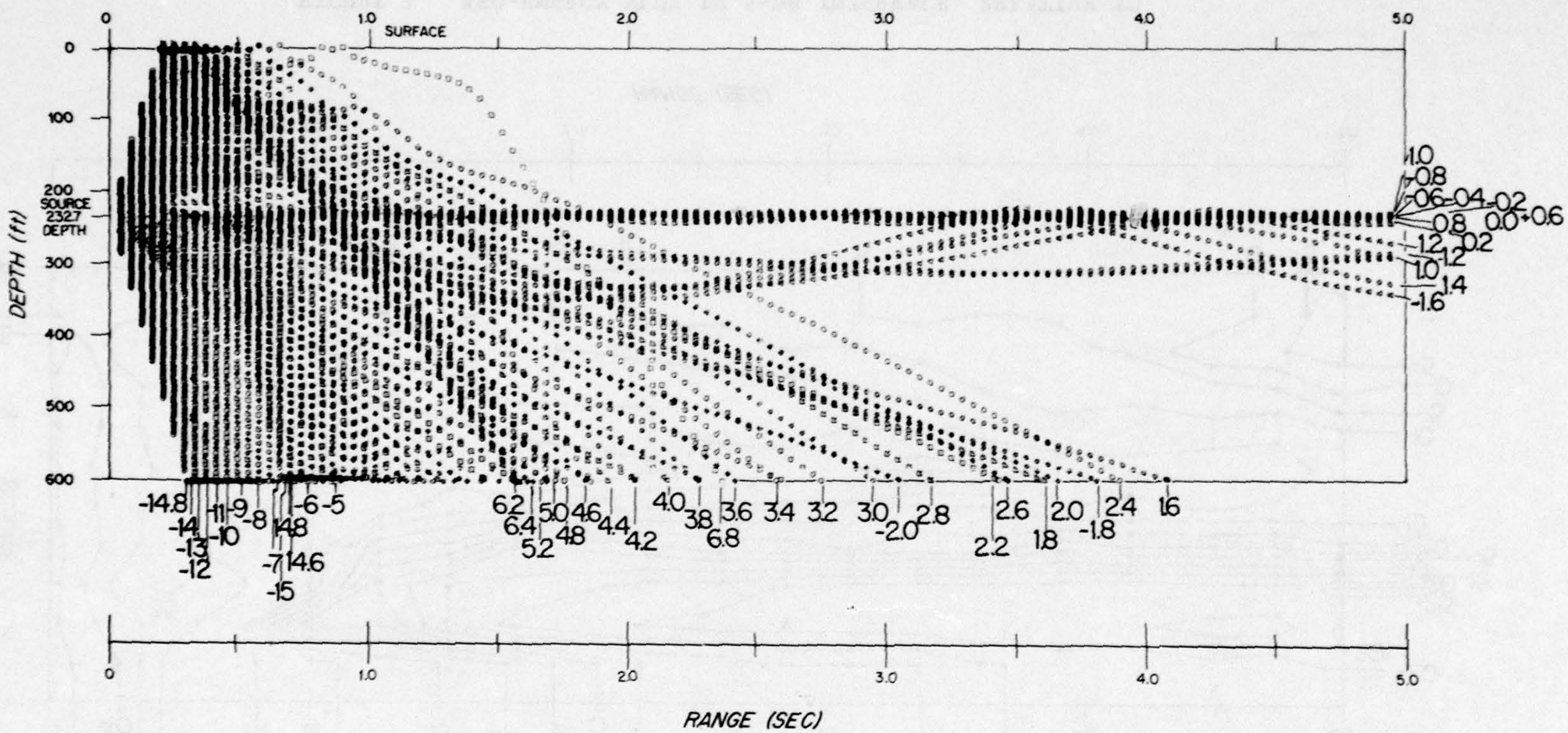

FIGURE 2. THEORETICAL RAY DIAGRAM.

BOTTOM REVERBERATION

J. K. Hall and J. B. Hersey

Over the past decade, many bottom reverberation measurements have been made using a shallow TNT charge as the source and an omni-directional hydrophone to receive the sound scattered from the ocean floor. A wide geographical distribution was obtained to allow correlation of backscattering coefficients with different sediment types, bottom structure, and topography.

These backscattering coefficients are now being computed using the Institution's high-speed General Electric 225 digital computer. Magnetic tape recordings are played back through the Electronics Associates Model 45.001 Oceanographic Computer to produce a record of energy flux density as a function of time for one-third octave frequency bands between 100 and 10,000 cycles per second.

At present the data are analyzed using two different models. Both assume a point source very near the surface, isovelocity propagation, a flat bottom, and no penetration, but one assumes Lambert diffuse backscattering at the bottom. Modifications were made to both models to calculate the backscattering coefficients using energy flux spectrum levels at the bottom derived from the finite amplitude parametric equations of Arons (1954) and Weston (1960).

Values of energy flux density at closely-spaced time intervals are read off at each frequency and manually punched onto IBM cards. For every time point the program computes a backscattering coefficient from each model and its finite amplitude modification, and these coefficients are automatically plotted as a function of grazing angle and frequency on the Electronics Associates Dataplotter.

From these plots the oblique backscattering mechanism may be studied by observing variation of the scattering coefficients as a function of grazing angle, frequency, and physiographic province.

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CORRELATION OF ECHO-STRENGTHS IN HIGH-FREQUENCY ECHO-SOUNDING, WITH MASS AND GRAIN-SIZE CHARACTERISTICS OF BOTTOM SEDIMENTS

L. R. Breslau and J. B. Hersey

During the past year an analysis of echograms and samples of bottom sediments taken along the same profiles in shallow water has been completed. The echograms, recorded during the familiar echo-sounding process using short pings of 12-kcps sound, were designed to display both peak-to-peak amplitudes in the echo and the total energy of the echo-train of the first bottom-reflection. From these, the apparent acoustical reflectivity was computed using suitable models of sound transmission through the water and of the reflection process. The reciprocal of reflectivity, expressed in decibels as bottom loss, was found to be correlated directly with the porosity or with the silt-plus-clay fraction of the sediment forming the sea floor at the same place (Fig. 1). While this sort of result is known from other work, nevertheless the present demonstration is especially valuable because a very detailed, yet extensive set of comparisons was made possible by intensive use of automated and semi-automated data collection and analysis techniques. This procedure has been developed to such a state that it readily can be fully automated and used as a routine survey tool of high reliability on a ship underway at cruising speed.

The absolute value of bottom loss was found to compare well with the reciprocal Rayleigh reflectivity. The departures from agreement probably are due mainly to errors in acoustical and electrical calibrations, which may be appreciable, and to failures to sample the bottom at the same locations as the echo soundings.

IN SITU MEASUREMENT OF ACOUSTIC ABSORPTION IN SEDIMENTS USING A SEISMIC REFRACTION TECHNIQUE

Lee C. Bennett

The frequency dependence of acoustic absorption is thought to be responsible for the differential penetration of some seismic frequencies into bottom sediments. Consequently, the measurement of acoustic absorption is of interest to seismologists, and an attempt to make in situ measurements was continued this year.

The method chosen for the study was the measurement of the attenuation, as a function of range, of acoustic waves which have

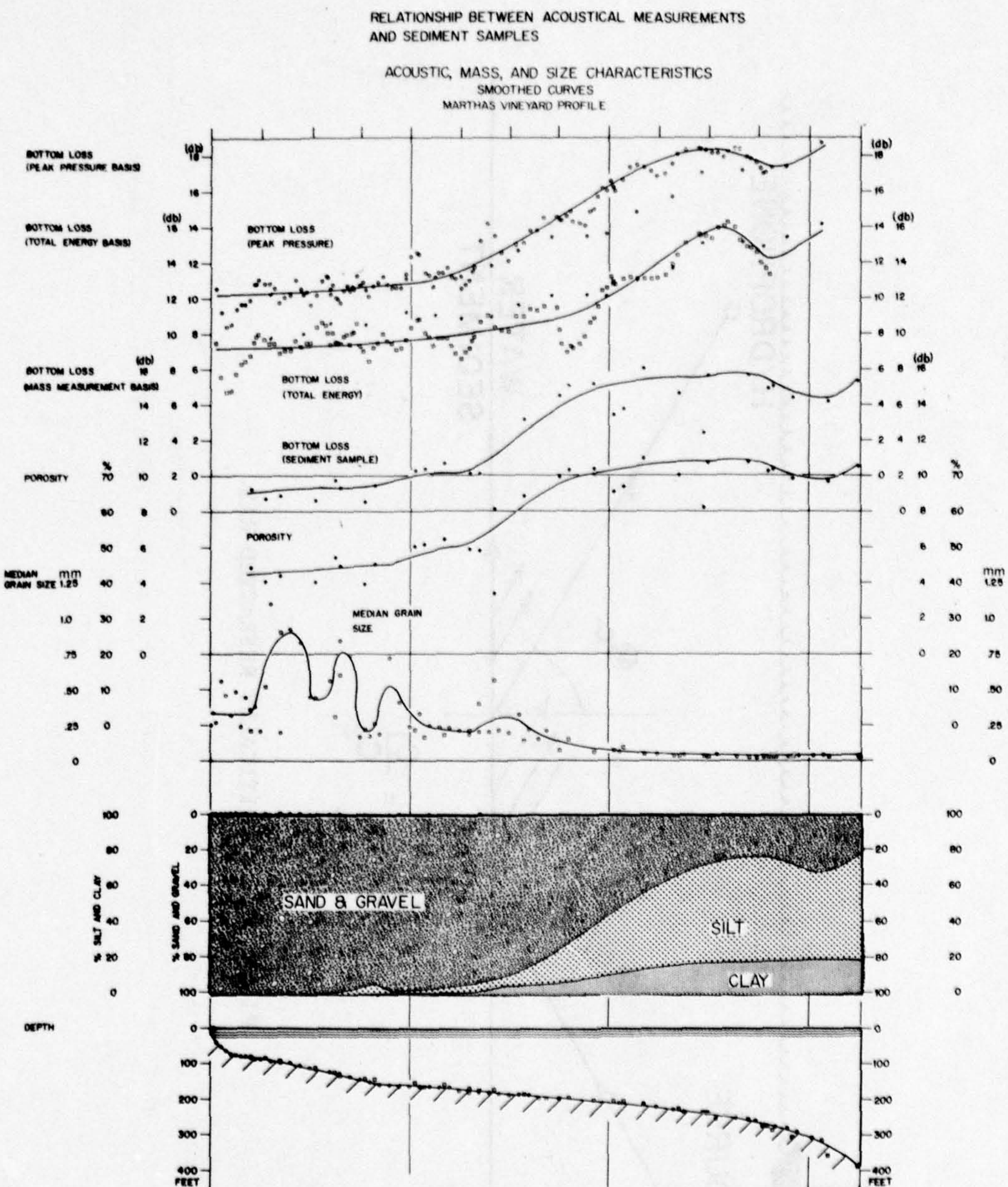

FIGURE 1. RELATIONSHIP BETWEEN ACOUSTICAL MEASUREMENTS AND SEDIMENT SAMPLES

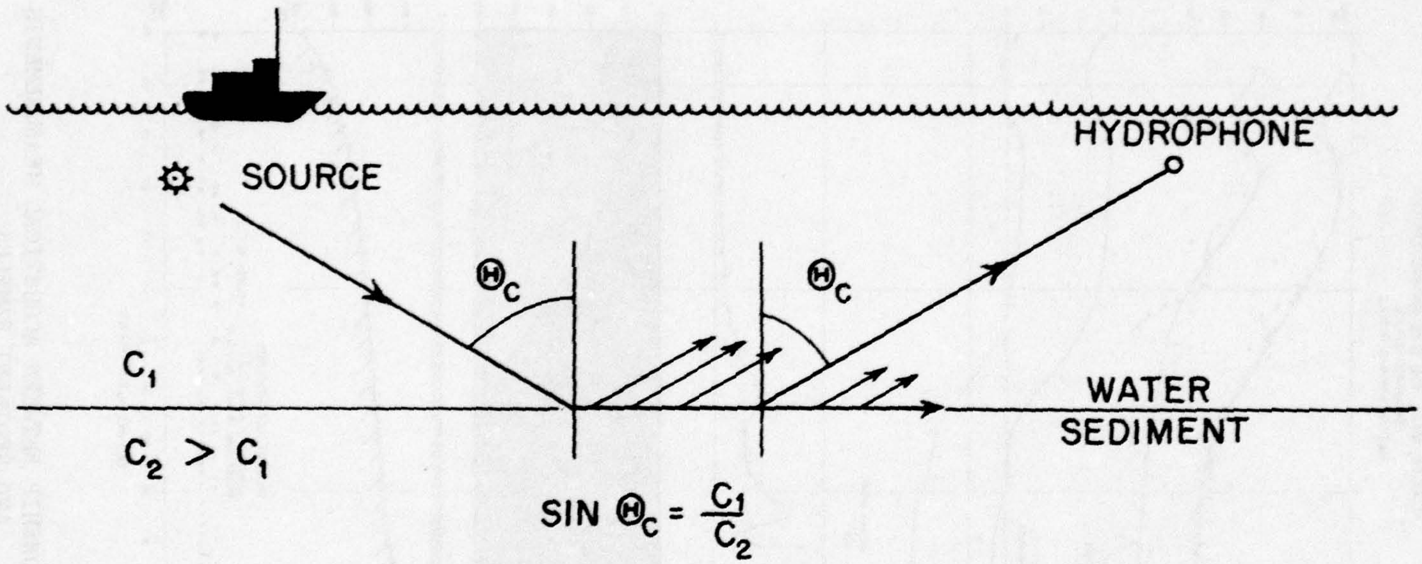

FIGURE 1. A CRITICALLY REFRACTED RAY.

been critically refracted in the bottom or sub-bottom strata (Figure 1). These echoes and others from repeated Sparker and Boomer pulses are recorded on magnetic tape and later played through band-pass filters to an oscillograph. The appropriate phases are identified and measured on the oscillograph record and the attenuation is determined by comparison of successive pulses.

The attenuation so determined consists of contributions from true absorption in the sediments, geometrical spreading, and loss of energy by diffraction and scattering. Several models have been considered this year to account for the losses other than absorption, but none was fully successful. This investigation is continuing using simple models and data from local areas in Buzzards Bay and the near-by continental shelf.

NATURAL SOUNDS OF THE SEA

William E. Schevill

For some time Dr. Carleton Ray of the New York Zoological Society had been suggesting that we listen for underwater sounds made by their captive pinnipeds, since these animals might be expected to use acoustics and especially echo-location in their natural habitat. In January we visited the Society's Aquarium and Zoo, and succeeded in recording from six species of pinnipeds some very faint sounds. These were for the most part impulsive clicks differing in structure from the familiar clicks of porpoises; the seal clicks had a definite and variable harmonic structure. The faintness of these sounds throws some doubt on their suitability for long-range echo-location in hunting and navigation; it may well turn out that the animals can make louder noises. We published a discussion of these sounds with spectrographic analyses (Schevill, Watkins, and Ray 1963).

For the last dozen years underwater listeners have been detecting intense low-frequency sounds near 20 cps in many parts of the ocean, including our coasts. These sounds, inaudible to human ears, but not so to sensitive listening systems, have greatly puzzled marine acousticians. Although most investigators have emphasized the rhythmic regularity of the signals (for example, a one-second pulse at 7, 11, 7, 11 seconds and so on, or again 12, 12, 12, 12), we have found that for much of the time the sounds are random, being regular only some of the time. These signals have been attributed to geological or meteorological causes, including microseisms, aircraft, ships, politics, and

animals, including whales, fishes and crustaceans. We soon became convinced that animals were responsible, but were unable to determine which. Other workers had offered whales, but we discounted these suggestions because we had never heard such sounds when recording cetaceans, and because whale sightings were usually not associated with the reports. However, the widespread distribution and the strength and low pitch of the signals made whales attractive suspects.

We continued to listen for and record these mysterious sounds, both from ships and shore stations, such as one in Maine obligingly turned over to us by the Bell Telephone Laboratories; we often used airplanes and blimps for spotting.

Although we had a few hints, plainer in retrospect than at the time when they were masked by conflicting and inconclusive data, it was not for several years that the evidence was clear that the 20 cps signals were definitely associated with a whale, and a particular one at that, _Balaenoptera_ _physalus_, the common and cosmopolitan finback. We now concentrated on this species, while continuing to check others, and found that the 20 cps signal was associated only with _B_. _physalus_, never with any other species encountered. A more dramatic check was made one November in Nova Scotia, where the sounds were regularly noticed and where these whales were unreported. It looked like a good test of our theory. The Royal Canadian Naval Research Establishment most hospitably allowed us to use a listening station, and we went there with our Helio Courier float plane. For several days one of us flew over the area while the other maintained a listening watch. Finally the listener radioed that he had the signal, and we in the plane found three finbacks in the hydrophone area.

This whale, _Balaenoptera_ _physalus_, is practically cosmopolitan, more so than the 20 cps signal has been so far reported, which is of course no more widely than the distribution of listening equipment able to hear this low frequency. It is believed that this signal has been noticed only in the last dozen years because it was only about then that sufficiently sensitive listening gear came into use.

The problem is not yet fully solved; for example, it may turn out that other species of _Balaenoptera_ may be involved, perhaps in other rhythms or even other frequencies. However, we feel that we are far enough to report on it, and did so last April at the Symposium on Marine Bio-Acoustics at Bimini (Schevill, Watkins, and Backus, 1964).

In the laboratory, analysis of records has continued,

especially the further study of pulses and pulse-like sounds of whales and seals. Part of this is reflected in the paper on Physeter clicks reported by Dr. Backus.

Mr. Watkins has designed and constructed a simple variable-reluctance hydrophone for general use, suitable even for amateurs (Watkins, manuscript), and also a "real time" concurrent frequency indicator (Watkins, manuscript). He also evaluated twenty different types of magnetic tape to determine which were most suitable for analog broad-band direct recording. In September he published a description of our portable recorder (Watkins 1963).

Several visitors have worked on our animal material. Mr. H.R.Frey of the United States Rubber Company made some measurements of porpoise skin, Dr. Allen Wilson of Brandeis University took some samples of muscle and viscera of pelagic and fresh-water porpoises for an enzyme study, Dr. Roger Atwood of the Thorndike Laboratory, Boston City Hospital, made some reconnaissance studies of the intestinal flora of the same porpoises, and Miss B. Lawrence of the Museum of Comparative Zoology dissected the laryngeal region of a *Stenella styx*. Messrs. M. L. Hanson and D. J. Harris of United Aircraft (Bio-Science and Technology Department) were given anatomical material for study, and several students at the Marine Biological Laboratory were helped similarly.

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Watkins, W. A. A simple variable-reluctance hydrophone.

Watkins, W. A. A real-time sound spectrum indicator.

SPERM WHALE CLICKS

Richard H. Backus and William E. Schevill

Sperm whales utter a characteristic click which we have heard in more than 20 encounters with these animals. A principle function, induced from the click-function of another odontocete, is assumed to be echo-locational. As in most clicking sounds the spectrum is broad, but the dominant frequency lies near five kcps. Repetition rates are low compared with similar sounds from other odontocetes, the highest so far noted being about 50 per second while a commonly observed rate is about two per second. Oscilloscope photographs show that each click is actually a series of shorter events which we call pulses. Clicks studied vary from one to nine pulses per click and the range of click durations so far observed runs from two to 24 milliseconds. The production of these multi-pulse clicks we call "burst-pulsing", a term taken from "sonarese. It is a familiar trick in sound-ranging when background noise is high.

Individual whales produce clicks which are highly reproducible, that is, succeeding clicks in a series are very nearly identical with one another. This phenomenon we call "signature". It may be useful to a whale in distinguishing echoes from his own clicks while discriminating against echoes from the clicks of others and also in recognizing other individuals important to him.

A happenstance recording of sperm whale clicks (as noise) on an echo-sounder record together with echoes from the whale making the clicks has allowed us to learn something of the timing performance and behavior of a sperm whale under a particular set of circumstances. The sperm whale's sense of rhythm, or ability at time perception, is most excellent. The "jitter" in intervals between successive clicks, when the repetition rate was about two per second, is about half of that of the best of human performers tested in the laboratory.

The fact that two whales in deep ocean situations of differing geometry had about the same click repetition rate (about two per second) and that this same rate has been observed commonly in tape recordings suggests that this rate is one employed when the whale is operating in a search mode (search as opposed to inspection) and that the 1200-foot stretch of water immediately ahead of him is the stretch he can efficiently examine when looking for weak sound-scatters such as squid.

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UNUSUAL SOUND-SCATTERING LAYER OFF NORTHEASTERN UNITED STATES

Richard H. Backus

Widespread exploration with a 12 kcps echo-sounder during the last decade in the western North Atlantic has uncovered an apparently unique sound-scattering layer which is confined to the slope water off the northeastern United States. The shoreward limit of the area in which this feature has been observed is about at the 200-fathom curve; the seaward limit is the warm front of the Gulf Stream. Between these limits the feature has been observed from off Cape Hatteras northeastward to the meridian of 65°W. This layer has the general properties of ordinary deep scattering layers save in the structure of the echo sequences on the echo-sounder record. Successive trains of echoes, instead of forming the usual even stripe resulting from the receipt of sound scattered by numerous targets of low reflectivity, form crescentic echo sequences resulting from the receipt of sound scattered by a few targets of high reflectivity. Such crescentic echo sequences are familiar features of echo-sounder records made in shallow water, especially over known fishing grounds, but are of infrequent occurrence at depth in the open ocean.

These crescentic echo sequences are arranged to form a layer whose midday depth is about 180 fathoms. The layer migrates to or near to the surface in the evening and away from the surface at dawn. These vertical migrations are slower and begin sooner than those of the ordinary deep scattering layers seen in the area with the 12 kcps echo-sounder.

In 1959 this peculiar layer was virtually continuously distributed over thousands of square miles of the slope water area from Cape Hatteras to the meridian of 71°W. In 1960 and 1961 the layer was very patchily distributed in this area.

An examination of the broad-band sound-scattering properties of this layer has been made during an evening vertical migration. At midday depth or near it the layer scatters sound which is sharply peaked near 12 kcps. This explains the very high intensity of the echoes recorded by the 12 kcps echo-sounder. During the evening ascent the layer best scatters sound at lower and lower frequencies. Near the top of the ascent at 15 fathoms the sound-scattering peaks between 2 and 3 kcps. Such a considerable change in peak scattering frequency indicates a gas-bubble scatterer, doubtless the swimbladder of a fish. Consideration of the depth-frequency relationship during the migration suggests that the fish was heavy at depth and simply let the swimbladder expand with lessening pressure to bring the fish to neutral buoyancy when near the surface. The surface swimbladder volume of the scatterer has been computed using the frequency-depth relationship and indicates a fish whose total displacement volume is about 40 cc.

Fishing with a large mid-water trawl has not yet assisted in the identification of this sound-scatterer nor have observations with an echo-sounder-camera apparatus been successful. One fish under consideration is the little known but apparently abundant gempylid, _Nealotus tripes_ Johnson. This bathypelagic fish has been observed in great numbers at the sea surface at night shortly after the evening ascent of the layer in question. The displacement volume measured for a number of specimens collected at such a time is smaller by a factor of two or three than that computed from acoustical data. (Abstract of paper delivered in the Specialized Symposium entitled "The Deep Scattering Layer", August 21, 1963, XVIth International Congress of Zoology.)

MESO- AND BATHYPELAGIC FISHES

R. H. Backus, Giles W. Mead and Others

Bathypelagic fishes collected on ANTON BRUUN Cruise 3 of the International Indian Ocean Expedition were returned to Woods Hole in October and were sorted preparatory to study group by group by Backus, Mead, Gibbs (USNM), Cohen (USFWS), and Ebeling (UCSB). These collections were made from about 12°N to 44°S along the

meridian 60°E. Similar collections are to be made in the spring of 1964 during ANTON BRUUN Cruise 6. The collections of the two cruises will be studied zoogeographically and ecologically in relation to Indian Ocean water masses.

Thirty-three collections of mesopelagic fishes were made on CHAIN Cruise 35 in deep water off the coast of South America during February. These collections, now sorted and mostly identified, were taken along a track parallel to, but 900 miles west of, one along which similar collections were made in 1961 during CHAIN Cruise 17. These CHAIN collections are part of a long-range study of the zoogeography, vertical distribution, systematics, and relation to sound-scattering of Atlantic Ocean meso- and bathypelagic fishes. Initial study of the CHAIN-17 fishes is complete (Backus, et al., ms). In addition to a systematic list of the fishes collected, consideration has been given to the nature and location of the faunal boundaries crossed during CHAIN's passage from the Romanche Trench (on the equator at 17°W) northwest towards Bermuda. A method for locating such boundaries from collections made along a long, straight track has been developed. The method is derived from the simple device of detecting intervals of greatest faunal change by adding the number of species collected for the first time at a station to the number collected for the last time at the preceding station. The method takes into account the fact that, in a homogeneous population, "first-time" captures become less and less probable as the sampling continues while the reverse is true of "last-time" captures. Application of the method to the fish data showed two boundaries of seeming significance. One occurred near 15°N and is apparently coincident with northernmost penetration of South Atlantic Central Water into the North Atlantic. The second, and less marked, near 23°N appears to coincide with the southern boundary of the Sargasso Sea as defined by the superabundance of 18°water.

On CHAIN Cruise 35, collections were made from near Guadeloupe (ca. 16°N, 61°W) southeastward to the equator. Although these collections are far from completely studied, they appear to show a faunal break near 6°N, 45°W where 200-meter temperature charts show a circular pond of cool water. The physical origins of this pond and the faunal boundary (if it indeed exists) are not at all understood.

<u>Reference</u>

Backus, R. H., G. W. Mead, R. L. Haedrich, Marion Grey, R. H. Gibbs, Jr. and A. W. Ebeling. (manuscript). Mesopelagic fishes collected in the tropical Atlantic Ocean during Cruise 17 of the R/V CHAIN.

PELAGIC SHARKS

Richard H. Backus

Sea trips of the last few years have given many opportunities for collecting data on pelagic sharks. Most shark knowledge is based on along-shore kinds and such common animals as the white-tip (Carcharhinus longimanus) have remained virtually unknown until within the last decade.

Data from several hundreds of captures by long-line and hook-and-line in deep water off northeastern United States have been reduced and studied. The common pelagic sharks here are (in approximate order of abundance): the blue dog (Prionace glauca), the white-tip, the silky shark (Carcharhinus falciformis), the mako (Isurus oxyrinchus), the dusky shark (Carcharhinus obscurus) and a hammerhead (Sphyrna lewini). The occurrence in the area of several species is seasonally limited. White-tips, for instance, move north of the Gulf Stream only in the warm season. Sexual segregation is a marked feature in the lives of some. The blue dog population, which is so large in New England waters during the summer, consists wholly of males. Many other complexities in the natural history of these interesting animals are unfolding.

A paper, which straightens out a taxonomic confusion in the case of the silky shark was completed during the year (Garrick, Backus and Gibbs, in press).

Reference

Garrick, J.A.F., R.H.Backus, R.H.Gibbs, Jr. Carcharhinus floridanus, the silky shark, a synonym of C. falciformis. Copeia. (in press)

AGE AND GROWTH IN THE BLUEFISH (Pomatomus saltatrix)

Richard H. Backus and Barbara Jones

Remarkably little is known of the life history of this important and sometimes abundant fish. Save for fragmentary information on the Black Sea stock, the only concrete age-growth data were published in a short note two years ago (Backus, 1962) but concerned a very small sample. Nonetheless, they showed that the bluefish grows remarkably rapidly (reaching a length of about 15 inches when little more than a year old) and probably comes to sexual maturity at an early age. Now we have made age determinations for a sample of 670

specimens and derived growth statistics from these data, fish length, and time of capture.

Reference

Backus, R. H. 1962. Age in a small sample of bluefish (Pomatomus saltatrix (Linnaeus)). Breviora 159:1-4.

BIOLUMINESCENCE

Richard H. Backus and Asa Wing

Around-the-clock observations of bioluminescence in Woods Hole Harbor have been made for several years by pumping water through a darkened chamber, detecting the flashes of animals with a photomultiplier tube, and tallying the flashes as a function of time. There is a marked diurnal rhythm in the bioluminescent activity observed in this way. Flash counts are low during the day and high at night with rapidly changing counts near sunrise and sunset (Backus, Yentsch and Wing, 1962). A goal is to get eventually some picture of seasonal rhythms at Woods Hole.

The most interesting observations made in 1963 were on the day of the solar eclipse, July 20. The sudden diminution of ambient light with the occlusion of the sun was accompanied by an increase in luminescence. When the sun was uncovered luminescence decreased but (the eclipse took place late in the afternoon) did not return to normal pre-sunset level before it began the regular evening increase. A similar behavioral pattern was noted in records of deep scattering layers made by Robert C. Clark at a station between Woods Hole and Bermuda at the same time. These two bodies of data are under consideration together.

Bioluminescence observations have been made over the deep sea and show that a diurnal rhythm such as that observed at Woods Hole, exists down through the euphotic zone. Deep-sea bioluminescence data are being studied together with Charles S. Yentsch and considered in relation to ambient light levels, water transparencies, and photosynthetic rates.

Reference

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STUDIES OF *DEEP-SEA FISHES*

Norman B. Marshall[1]

My work at Woods Hole Oceanographic Institution began with an EQUALANT Cruise on R/V CHAIN during February, when R.H.Backus and I made a series of mesopelagic fish collections with an Isaacs-Kidd trawl (mainly at the depths of deep scattering layers).

On returning to Woods Hole, one of my first tasks was to prepare a series of 10 lectures, which were given at Harvard University Biological Laboratories between April 9 and May 9. The first lecture was on the rise and success of the teleost fishes; the second to fourth on the physical and biological structure of the deep ocean in relation to the life of fishes; the fifth on sound production in fishes, with special reference to the deep sea; the sixth and seventh on form, fin patterns, and locomotion in fishes; the eighth on buoyancy in fishes; and the last two on aspects of convergent evolution in fishes. This series of lectures is to be published as a book.

In connection with the work of R.H.Backus on the trichiuroid fishes, I have examined the swimbladder structure of a number of species. All except Lepidocybium and Ruvettus have a well-formed swimbladder. Apart from throwing light on the relationships of trichiuroid and scombroid fishes, the work has a bearing on fishes as sound scatterers in the deep ocean. A paper on this work is in preparation.

One of the main objects of my visit here is to continue work on the macrourid fishes and I am preparing a paper on those that are found in the Western North Atlantic. This will be published in the Sears Foundation series on the Fishes of the Western North Atlantic. This work also has a bearing on the Institution's interest in sounds in the sea. Except in a few species, the males have well-developed drumming muscles on the swimbladder, which I have also found in brotulid fishes. This means, most likely, that about half of the species of deep-sea benthic fishes must be able to produce sounds. (Macrourids and brotulids together number some 500 species.)

Together with D.W.Bourne, I have prepared a paper on the population density, diversity and habits of deep-sea fishes in

[1]Mr. Marshall, Senior Principal Scientific Officer at the British Museum (Natural History) began a two-year visit at the Woods Hole Oceanographic Institution early in 1963 and has been supported by NSF grant 20702.

the Red Sea and Gulf of Aden. This is based on bottom photographs taken during ATLANTIS Cruise 196 by J.W.Graham. Bourne and I are also examining photographs taken during the search for THRESHER. These records, combined with others, should enable us to estimate the population density of fishes at different depths in the North Atlantic.

DIRECTIONAL SPECTRUM OF INTERNAL WAVES

Henry T. Perkins

With the advent of towed thermistor chains it has become clear that internal waves, seen as irregularities in isothermal surfaces, are a very widespread feature of the upper 100 meters of the ocean. During 1963, in cooperation with Arthur Voorhis, observations of these irregularities were continued and techniques were developed for analyzing them.

During the first half of the year, observations of internal waves were made by continuously recording the output of a single thermistor towed at a depth of about 100 meters while the ship steamed the courses 45^{o} apart which construct an eight-pointed star (figure 1). This was done in March during CHAIN Cruise #35 while on the equator at about 30^{o}W and again in June during CRAWFORD Cruise #93 while about 100 miles northwest of Bermuda. In both cases, the thermistor was towed nearly on the axis of a well-developed seasonal thermocline.

The general procedure for analysis has been to compute the apparent spectrum of the observations along each course and to transform these spectra into the true directional spectrum, giving energy densities as a function of wavelength and direction of propagation. Tentative results have been obtained for the CRAWFORD data which agree with results reported by Voorhis in the "Summary of Investigations" for 1962 (WHOI Ref. No. 63-18, pt.5, p.29). The power density increases rapidly with increasing wavelength starting with a wavelength of 2 km and extending through 10 km, the longest wavelength that could be resolved.

Another interesting feature of the spectrum is that the waves in the 0.5 km to 2.0 km wavelength band show a strong tendency to propagate along a northwest-southeast line. Unfortunately, statistical instability of the spectral estimates together with the shape of the spectrum combine to prevent us from eliminating the 180^{o} ambiguity.

While the above measurements were being made, a recording thermometer was suspended from a radio beacon at the same depth as the thermistor was being towed. The assembly was attached to a drogue and allowed to drift (figure 1). This yielded a spectrum of periods with much the same characteristics as the wavelength spectrum. The energy density increased rapidly as the period increased to 6 hours, the longest period that could be resolved.

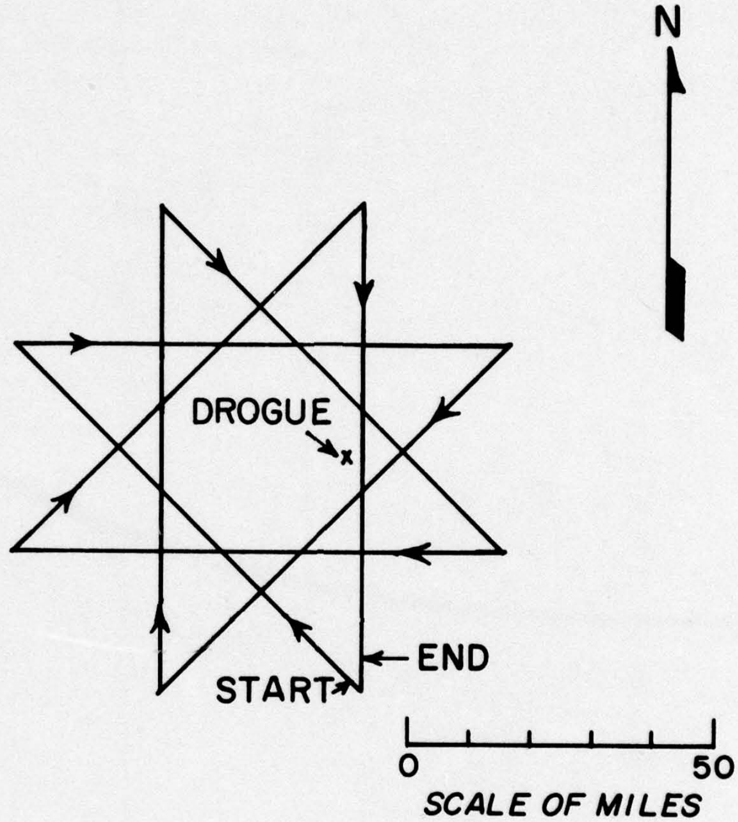

FIGURE 1. TRACK OF CRAWFORD WHILE MAKING OBSERVATIONS OF INTERNAL WAVES.

CRUSTAL GEOPHYSICS

SEISMIC STUDIES OVER THE OUTER RIDGE NORTH OF PUERTO RICO

Elizabeth T. Bunce, J. B. Hersey, and D. A. Fahlquist

Interest in the crustal structure of the Outer Ridge and its shallow mantle, shown in the crustal section by Bunce and Fahlquist (1962), has resulted in further investigation of the Ridge by seismic refraction and reflection techniques, including continuous seismic profiling.

Continuous seismic reflection profiles were made over most of the existing seismic refraction profiles during CHAIN Cruise 34. Correlation of the reflection horizons with the layers determined from the refraction profiles has identified the major reflector observed on all profiler traverses over the Outer Ridge with the 5.5 km/sec velocity layer.

The refraction results showed a shallow mantle occurring in a small section of the Outer Ridge, these results being corroborated by continuous gravity measurements made during the cruise. The continuous reflection profiles did not show details of structure below the 5.5 km/sec layer but clearly delineate this surface and those above it. The compressional velocities of rock samples from the north wall of the Puerto Rico Trench described by Hersey, et al., (1964) suggest that the 5.5 km/sec layer may outcrop there at depths of about 6 km.

A joint cruise of ATLANTIS II (Cruise 6) and CHAIN (Cruise 36) was planned to use the same combination of seismic techniques along an east-west line located to yield the best information on the structure of the shallow mantle underlying the Ridge. We were unable to make continuous seismic profiles during the refraction shooting but were able to substitute very closely-spaced shots for it. It is apparent that the deep crustal structure so determined is complex but details must await further analysis.

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SEISMIC REFRACTION OBSERVATIONS ON THE CONTINENTAL BOUNDARY WEST OF BRITAIN

Elizabeth T. Bunce and J. B. Hersey

During CHAIN Cruise 13 a north-south seismic refraction profile (80 km long) was made on the continental shelf south of Ireland in collaboration with scientists of the Department of Geodesy and Gophysics, Cambridge University, and the National Institute of Oceanography who were aboard RRS DISCOVERY II. The interpretation of these data was completed during 1963 in cooperation with S. Crampin and M N. Hill of Cambridge.

One significant feature of this profile was the determination of a layer of high velocity, 7.76 km/sec, at depths of 15 km at the north end and 25 km at the south end of the profile. The velocity-depth relations for materials lying above this layer are presented in a structure section (Figure 1). Other features of this section are the truncated appearance of the basement and Paleozoic rocks (layers C and D) overlain by nearly horizontal layers of younger rock and sediment (A and B), and the horizontal change in thickness and velocity of these layers. These shallow structures agree with the trends described from previous results (Day, et al., 1956) for the area closer to the continent. High topographic relief, like that shown on the Layer-D surface has also been widely observed in the deep sea for the top of the crustal layer of intermediate velocity about 5.2 - 5.5 km/sec (Ewing and Ewing, 1963; Bunce and Hersey, 1963). More extensive comparison of relief of the continental and oceanic layers having velocities in this range might well aid in elucidating the history of each.

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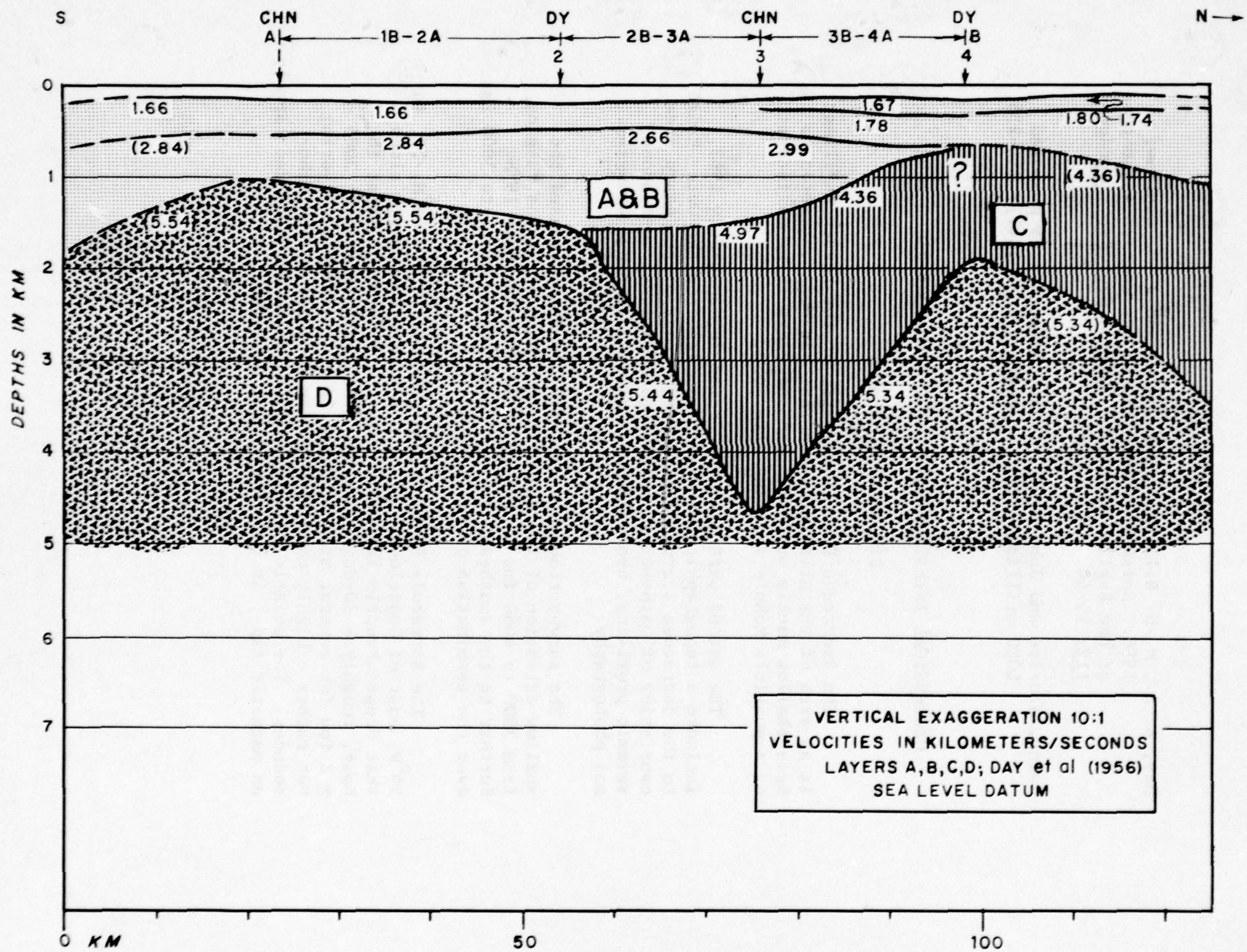

FIGURE 1. STRUCTURE SECTION OF SHORT PROFILES SOUTH OF IRELAND

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GEOPHYSICAL INVESTIGATION OF THE BARRACUDA FAULT ZONE

Elizabeth T. Bunce

The Barracuda Fault Zone, east of the Lesser Antilles, is an area of the Atlantic Ocean that has been suggested to have shallow mantle structure and therefore to be of interest as a possible Mohole drilling site.

The second part of CHAIN Cruise 36, June-July 1963, included a topographic and gravity survey from the Outer Ridge to the Barracuda Scarp and a detailed study of the scarp area consisting of bathymetry, gravity observations, continuous seismic profiling, heat-flow measurements, coring, dredging, and photography.

The survey tracks to and from the scarp crossed the shallow extension of the Puerto Rico Trench at depths ranging from 3900 to 4060 fms as far as 61°30'W at latitude 19°N. Further to the southeast the depths gradually shoal to 3000 fms over the termination of the Trench.

The Barracuda Scarp trends ESE near 16° to 17°N, 57° to 59°W, east of Guadeloupe. It has a precipitous north slope that drops abruptly from 2600 fms to a 3085-fm plain at the base, roughly a 30-degree slope. The plain is flat at 3085 ± 2 fms for several miles. There is no evidence of layering, but rather a highly compacted bottom is shown by the echo-sounder. The seismic reflection data, which was recorded largely on magnetic tape, is currently being analyzed.

THE STRUCTURE OF THE ABYSSAL HILLS SOUTHEAST OF BERMUDA

Richard L. Chase and Elizabeth T. Bunce

Between the mid-oceanic ridges and the continental rises lie the abyssal hills and plains of the deep ocean. The plains, flat areas floored by layered sediment, are the recipients of sediment carried from the continental slopes by turbidity currents. The hills, more rugged areas, seem to be regions of the ocean bottom which turbidity currents have not yet covered. Southeast of Bermuda, bounded to the north and southwest by the Sohm and Nares abyssal plains, and protected from continentally-derived material from the northwest by the Bermuda Rise, lies a large area of abyssal hills which was visited by CHAIN during September, 1963, (Cruise #39).

The dominant structural pattern in the region is inferred to be a system of ridges and valleys trending nearly north-south. This inference is made because (1) analysis of echo-sounding records of several cruises across the whole province shows that the average distance from the crest of one topographic rise to the crest of the next is shortest in an east-west direction, and (2) ten closely-spaced east-west traverses in an area sixty miles square show that discontinuous north-south ridges do exist within this area. However, isolated hills and valleys within the area of detailed survey demonstrate that some structural elements are not part of the north-south pattern. Traverses east-southeast across the whole abyssal hills province show several small flat-bottomed valleys floored with finely-layered sediment. These valleys may connect with the Sohm or Nares abyssal plains to the north and south of the abyssal hills. Echo-sounding records from previous cruises show that such valleys are wider and more common to the north toward the Sohm abyssal plain.

Continuous seismic reflection profiles of the abyssal hills show that a major reflecting surface of high and irregular relief lies within a few tens-of-fathoms of the sea-bottom except in sediment-filled valleys. The reflector probably represents volcanic rock or consolidated sediment. To the north-west, in the Bermuda rise, a reflector of similar intensity but lower relief lies at a much greater depth beneath the sea-bottom, overlain by shallower reflectors. Of the thin veneer of sediment overlying this reflector in the abyssal hills, only the surface was sampled. Red clay was recovered in eight dredge hauls and a number of heat-probe cores. Manganese nodules were found in

one dredge haul. Fragments of altered mafic rock, probably basalt, which form the nucleii of the nodules, indicate that such rock is at or close to the surface of the sea floor in the vicinity of this haul (29°47'N, 59°39'W).

SEISMIC REFLECTION STUDIES ON THE CONTINENTAL RISE SLOPE AND OUTER SHELF SOUTH OF NEW ENGLAND

D. D. Caulfield, Hartley Hoskins and W. P. Horner

Study of the continental shelf, slope, and rise south and southeast of New England by means of seismic reflection profiles (Figure 1) has continued this year with the acquisition of fourteen additional profiles on cruises of ATLANTIS II and CHAIN. These profiles were made with the 100,000-joule Sparker and 7,000-joule Boomer sources and extend into deeper water than the earlier work with the 400-joule Sparker summarized by Knott, _et al_., 1963. Among these records were the first made with an improved detection system which includes a five-element towed array (Dow, Hoskins and Nowak, p. 151) and a matched-filter correlator system (Caulfield and Nowak, p. 149).

Three fifty-mile profiles and four ten-mile profiles taken in 1962 on CHAIN Cruises 22, 29, 30 and 31 have been examined. Each of the long profiles started in about 1500 fathoms of water and continued up onto the shelf to 80 fathoms or less.

Preliminary analyses consist of identifying and tracing the lateral extent of the sub-seafloor reflection and their presentation on a scale adjusted to a constant vertical exaggeration. The frequency-dependent absorption and reflection properties of the sediments along the profile taken on CHAIN Cruise 29 (Figure 2) were obtained by measuring the spectrum of successive echoes. Horizon "B" returns an echo predominantly in the band 60-120 cps, while the deeper horizon "A" lies predominantly in the 30 to 40 cps band.

These new profiles fill in gaps in earlier data and reinforce the conclusions of Knott, _et al_., (1963) that the sub-bottom layering on the shelf has an increasing southerly dip as one moves offshore and that many layers outcrop in submarine canyons and on the slope. The manner in which the sediments of the continental rise lap up onto the slope indicates that the rise is the result of erosion of the upper slope.

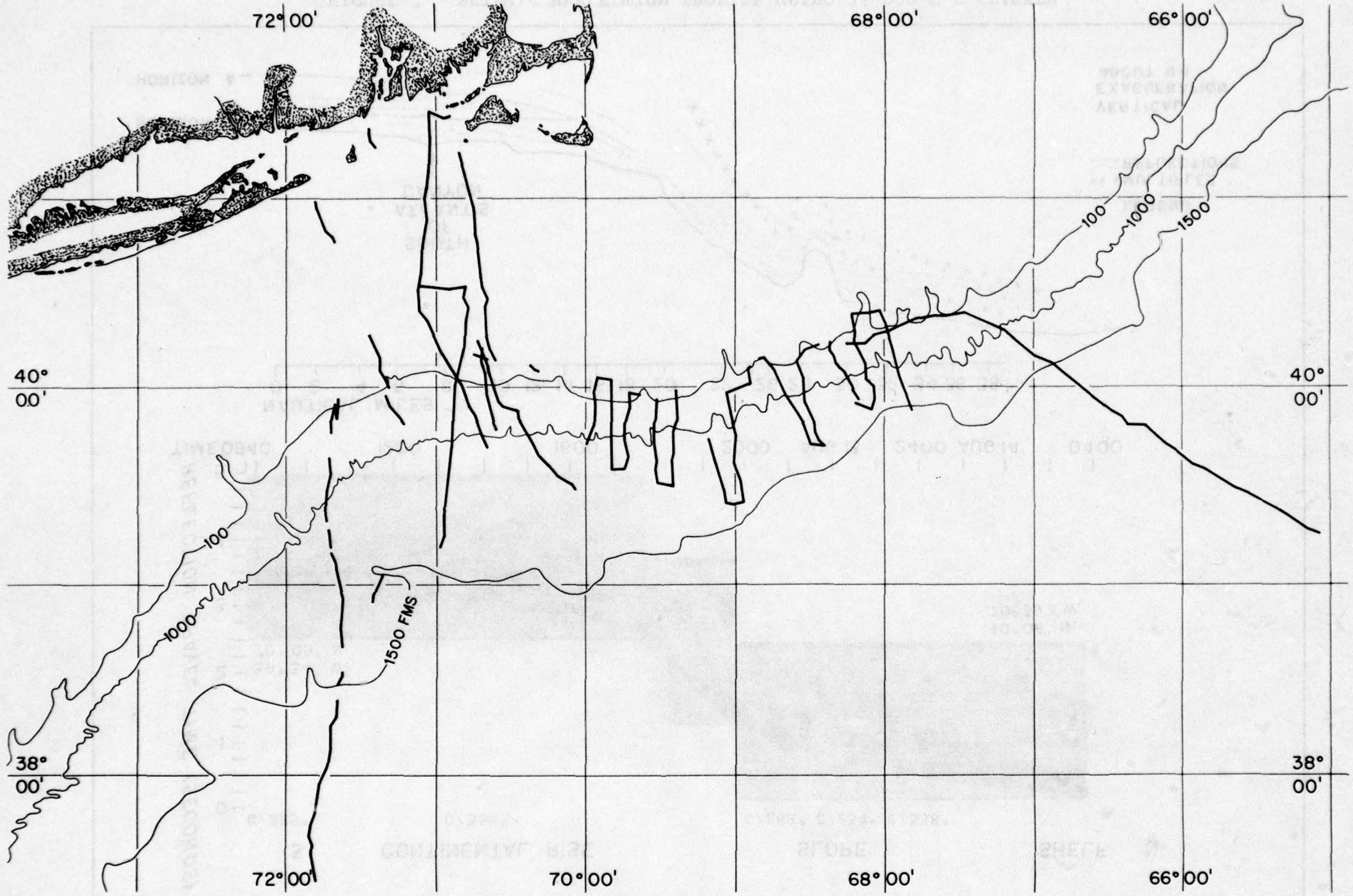

FIGURE 1. CONTINUOUS SEISMIC REFLECTION PROFILES USING 25,000 AND 100,000 W-S SPARKER, AND 7,000 AND 13,000 W-S BOOMER SOURCES. JANUARY 1962 TO AUGUST 1963. CHAIN CRUISES 22, 29, 30, 31, 34, 39. ATLANTIS II CRUISE 1. TOTAL PROFILE - 550 NAUTICAL MILES.

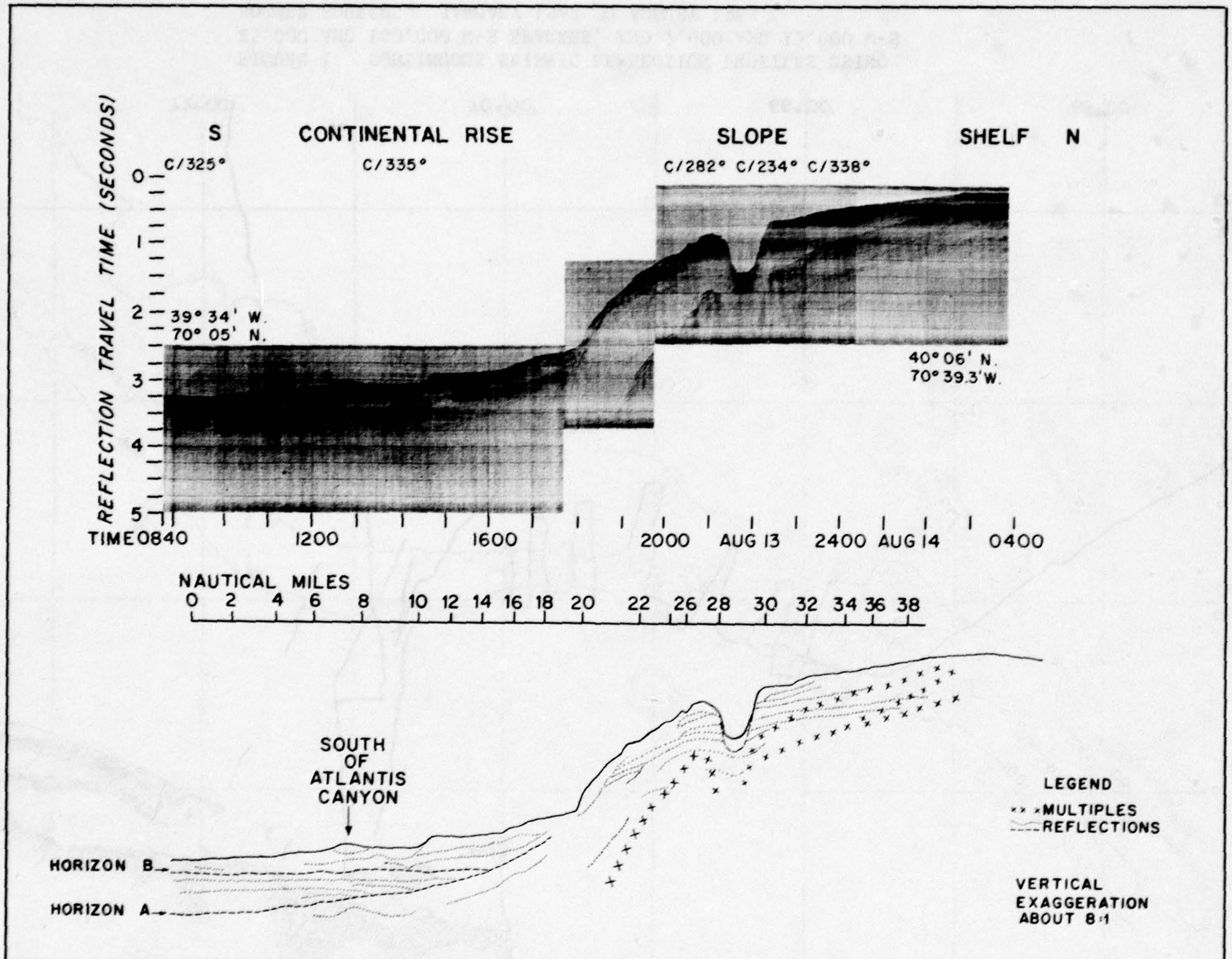

FIGURE 2. SEISMIC REFLECTION PROFILE USING 25,000 W-S SPARKER AND GEOLOGIC STRUCTURE INFERRED. CHAIN 29. 12-14 AUGUST 1962.

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GRAVITY INVESTIGATION OF THE REPUBLIC OF HAITI

Carl O. Bowin

During February 1963 a reconnaissance gravity survey was conducted in the Republic of Haiti. The survey consisted of 224 stations which have been reduced to Bouguer gravity anomalies. A contour map of the Bouguer anomalies reveals several interesting features. The most prominent of these features is an NE-SW trend in central northern Haiti that cuts across the trend of the Massif du Nord and the Central Plain of Haiti. A major gravity high, associated with the axis of a belt of metamorphic rocks in northern Dominican Republic and northeastern Haiti, is also terminated by this feature. To the west of the NE-SW trending gravity feature, another axis of high gravity occurs along the center of the Northwest Peninsula. If these two axes of positive gravity anomalies were once continuous, then the NE-SW trending gravity feature marks a zone of left-lateral displacement. It does appear on the basis of gravity measurements, however, that the westward continuation of the belt of metamorphic rocks on Hispaniola does not link up with the submarine rise connecting Cuba and Haiti at the northeast end of the Cayman trough.

No negative Bouguer anomalies were encountered in Haiti. This suggests that the large Tertiary basin underlying the Central Plain is not as deep as the Cibao Basin (-30 mgals), the Enriquillo Basin (-30 mgals), or the San Juan Basin (-40 mgals) occurring in the Dominican Republic. Further, the San Juan Basin, Sierra de Nieba, and Enriquillo Basin appear to be related to a larger feature which terminates westward in central Haiti.

The Cul de Sac - Enriquillo trough shows but a single minimum gravity anomaly, and this occurs in the approximate center of the trough. The Southern Peninsula of Haiti reflects neither a gravity high nor a gravity low, but is crossed by a gravity gradient with increasing positive anomalies to the south.

The gravity survey reported here is part of a continuing program of investigation on the geology and gravity field of Caribbean region both on land and at sea. The shipboard data-

processing system described elsewhere was developed to assist in this effort, and it has greatly facilitated the acquisition, reduction, and interpretation of the gravity and magnetic values obtained. A recent cruise of the CHAIN (41) was intended to investigate the gravity and magnetic fields, and bathymetry around the island of Hispaniola for assisting in the correlation of the island geology with the structure of the neighboring sea floor. Unfortunately, serious ship difficulties necessitated the abandonment of the scientific program off western Haiti.

CONTINUOUS SEISMIC-REFLECTION PROFILES SOUTHWEST OF BERMUDA

Sydney T. Knott

During ATLANTIS II Cruise 1, continuous seismic reflection data were recorded along tracks forming a fine grid over a small area southwest of Bermuda. These data were routinely recorded on magnetic tape but only a small fraction were satisfactorily presented on Precision Graphic Recorders (PGR). At considerable effort a portion of the tape-recorded data has now been analyzed by planing the tapes through filters and computers to a Precision Graphic Recorder. The signal quality and the signal-to-noise ratio on the tapes are equivalent at best to those received as the data are collected.

Two long profiles made southwest from Bermuda (Figure 1) have been analyzed. Navigation was by Loran C. The tracks are separated in some places the order of a mile or two. It is interesting to note not only the similarity between profiles but also the differences. Some features appear to be surprisingly local in extent by not appearing on both profiles, but further exploration of them was not possible at the time. Part of the profile suggests, bedding close to horizontal and trapped by ridges, but no evidence of this bedding appears on 12-kcps sounding records taken at the same time. Minimum thicknesses between these horizons (0.025 seconds travel time) is about an order of magnitude greater than that commonly observed between horizons revealed in echo sounding at 12-kcps. If the minimum dimension detected between horizons is an inverse function of frequency, then the fact that bedding shows at lower frequencies, but not at 12-kcps, would suggest that these thicker layers have a different origin: marine deposits indeed, but a homogeneous deposition over discrete long periods, or a deposition of a lot of similar material in a series of short periods. Another example of horizontal variability is the scarp which may be the result of

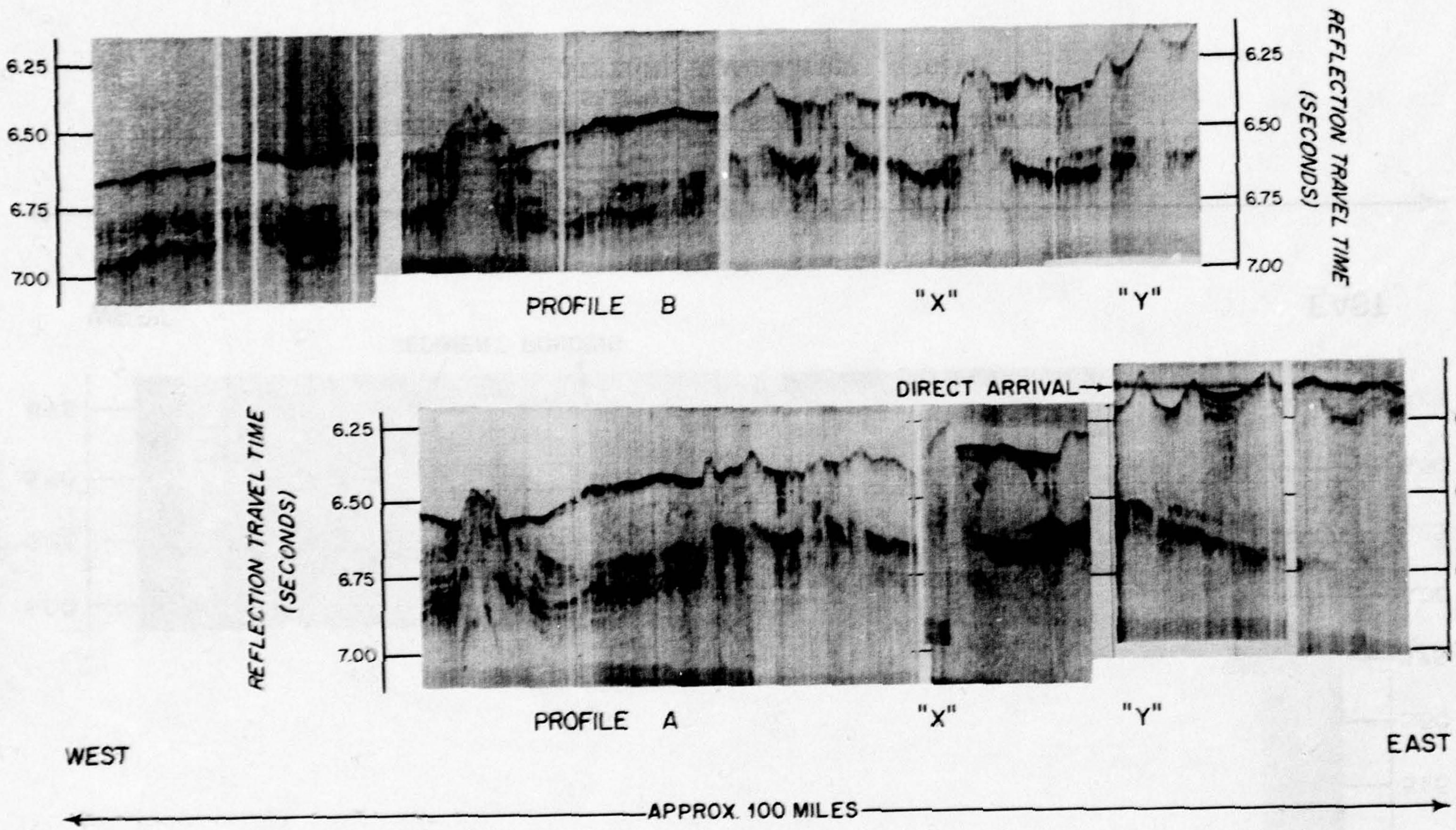

FIGURE 1. SEISMIC PROFILES SOUTHWEST OF BERMUDA
(VERTICAL EXAGGERATION 50:1)

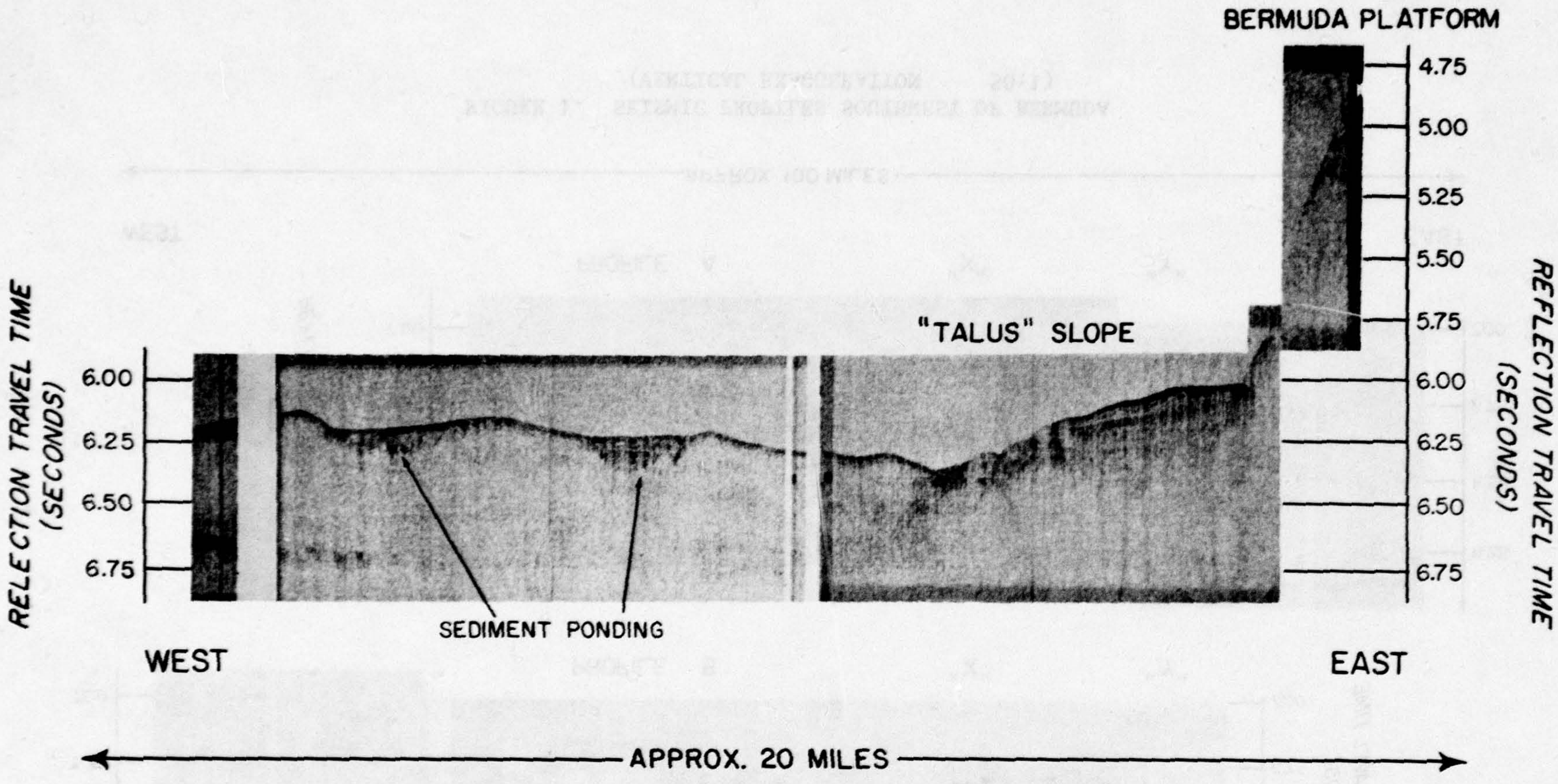

FIGURE 2. SEDIMENTS ON THE FLANKS OF BERMUCA DETECTED BY SEISMIC REFLECTIONS. (VERTICAL EXAGGERATION 10:1)

a fault suggested in the reflections at point X on profile A and which is less developed nearby in profile B. However, the deep reflection, which can be traced from the small, probably volcanic, seamount at the southwest, continues under this "fault" with no apparent interruption.

The overburden on this deep reflection horizon increases and its depth increases toward the Bermuda platform. We do not have sufficient data to demonstrate, but possibly the high points at Y extend laterally and are concentric to the island. If so they may be the result of plastic flow during the compaction and equalization of forces when the seamount was formed. Near the strong break in slope from the deep sea floor to the flanks of the island,occasional records (Figure 2) look like talus slopes.

HEAT-FLOW STUDIES

Francis S. Birch and A. John Halunen

Heat-flow measurements made on the Outer Ridge of the Puerto Rico Trench agree with previous work in that area. There is no correlation between heat flow and sediment thickness as measured by seismic reflection and refraction, probably because of the slow rate of sedimentation. Such small differences as exist are probably the result of basement relief.

The heat flow in the Barracuda Fault Zone is slightly below the world average both on the ridge and on the flat plain to the south. On the flat plain to the north the heat flow is definitely less than 50% of normal. This anomaly can be explained by rapid sedimentation into the filled trough beneath the plain and by differences in the thermal conductivity of the sediments, crustal rock, and mantle.

Heat flow around the New England seamounts is about normal. There is no correlation of heat flow with proximity to the seamounts or with sediment thickness. There is no indication that remnant heat from the volcanic seamount is affecting the heat flow.

Five heat-flow measurements made southeast of Bermuda may show that the "thermal plain" described by Reitzel (1963) is terminated near the boundary of the Nares Abyssal Plain and the Abyssal Hills. Heat flow about 200 miles southeast of Bermuda on the Bermuda Rise is above the upper limit of Reitzel's average

while those 500 to 600 miles southeast are below the average. One possible explanation of the high heat flow is that it stems from remnant heat from ancient vulcanism or crustal movement in the area. There is no satisfactory explanation of the low values. Additional work is planned in this area in the near future further to define the relationship of heat flow to geologic structure.

References

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HEAT-FLOW STUDIES in 1962

John S. Reitzel

Dr. Reitzel's report on heat flow was inadvertently omitted from the "Summary of Investigations conducted in 1962". The work he summarized in that report has since been published as "A region of uniform heat flow in the North Atlantic". J.Geophys.Res. 68: 5191-5196. This work was supported by Contract Nonr-1376(00) with the Office of Naval Research.

GEOLOGICAL INVESTIGATIONS

ANALYSIS OF DREDGINGS ON THE NORTH WALL OF THE PUERTO RICO TRENCH

R. L. Chase, J. B. Hersey, and C. O. Bowin

Further analysis of the dredgings taken from the north wall of the Puerto Rico trench during CHAIN Cruise 34 (Hersey, Nalwalk and Bowin, 1963) has yielded new information both about the rocks there and the techniques used to sample them.

Paleontological, petrological and geophysical studies have been made of a haul (CH 34-D3) of basalt, chert, porcellanite and limestone recovered from a depth of 6.1 to 6.7 kilometers at 20°16'N, 65°42'W on the north wall of the trench during December 1962. This work continues under contract Nonr-4029(00) and NSF Grant 822.

Paleontology

Miss Ruth Todd and Miss Doris Low, United States Geological Survey, have identified as Cenomanian a fauna of foraminifera from the limestone fragments obtained in dredge haul CH 34-D3 (Todd and Low, in press). Fossil assemblages from rock samples of previous dredge hauls from the same area (CHAIN 19) have been identified as upper Cretaceous and Paleogene (Riedel, W.R., written comm., June 1962). Still older rocks are known from the Greater Antilles; in Puerto Rico and Hispaniola, the oldest dated rocks are Aptian-Albian, and in Cuba, Jurassic.

Petrology

Of the three kinds of basalt brought up in the haul, the main types are porphyritic and amygdular basalt. A lesser quantity of slightly coarser basalt with rare amygdules and phenocrysts was also recovered.

The porphyritic basalt occurs as angular fragments weighing up to five kilograms and is coated on external and irregular internal surfaces with a soft green clay which is probably nontronite. The phenocrysts are bytownite (up to An 85 centrally, down to An 69 peripherally). The ground mass consists of microlites of less calcic plagioclase (down to An 38), green layer silicates and, in places, relict pyroxene. Both phenocrysts and ground mass are partly replaced by layer silicates. The only one of the latter which showed up on X-ray diffraction records of random and oriented powders of the rock is a mixed layer clay, two-thirds nontronite and one-third mica.

The amygdular basalt has 5% of its volume as spheroidal amygdules 0.3 to 2 mm in diameter and filled with calcite or radiating aggregates of nontronite. The body of the rock consists of laths of plagioclase (up to An 79 centrally, down to An 54 peripherally) and pyroxene, extensively altered to a yellow-green layered silicate which is identified as nontronite by X-ray diffraction study.

Samples of the third basalt type are less altered than those of the first two.

The three types of basalt may have come from different parts of a single basalt flow, or from several distinct flows. The smallness of the amygdules may be the result of a high fluid pressure due to an overlying mass of ocean water at the time of extrusion of the basalt magma. However, Engel and Engel (1963), in a study of basalts from the Northeastern Pacific Ocean, remark that there is no uniform decrease in vesicles in basalts as a function of the depth from which they were dredged.

The absence of indications of processes of albitization or chloritication in the basalts is in accord with findings of Engel and Engel (op. cit.) and Khorzhinskii (1963), in rocks from the Pacific and Indian Oceans. Oceanic basalts provide no support for the theory that basalt magma is converted to spilites during crystallization in the deep sea. However, the chlorite of spilites may be, in part at least, a product of the alteration of the nontronite of oceanic basalts under conditions of low-grade metamorphism.

Seismic Velocities

Professor Francis Birch of Harvard University has measured compressional velocity in samples of basalts, cherts, porcellanites and limestones. A summary of the values he obtained is given below.

These velocities accord well with velocities computed from seismic refraction data north of the Puerto Rico Trench. Bunce and Fahlquist (1963) show a layer up to one kilometer thick, approximately one-half to one and one-half kilometers below the sea bottom, with velocities of 5.1 cm/sec. The pressure on this layer is calculated to be about 1 kilobar, and it lies at the same depth as that from which the rocks were dredged. A mixture of porphyritic basalt (the most common type in the dredge haul) and chert would yield velocities close to this value under a pressure of one kilobar.

	Density	Velocity — Km/sec		
		1 atm.	1 Kilobar	4 Kilobars
amydgular basalt	2.69-2.70	4.37-4.57	4.89-4.95	5.42-5.48
porphyritic basalt	2.58-2.70	4.39-4.96	4.60-5.15	4.90-5.50
red porcellanite	2.08-2.18	3.59-4.28	3.78-4.29	3.96-4.30
chert	2.50-2.55	4.99-5.32	5.31-5.41	5.40-5.50
laminated gray limestone (sample crushed)	2.13	3.53	4.81	4.93

The accuracy with which it was possible to identify the location of the dredged site leaves little doubt that the mixture of basalt and chert obtained represents, at least in the immediate region of the dredge haul, the composition of the seismically-determined layer having a velocity of about 5.1 km/sec. However, material dredged at other locations suggests that the geology of the north wall is complex. Serpentinized peridotite was obtained from the main scarp of the north wall near 66°30'W and it appears that the stratigraphy there is serpentinized peridotite with minor altered basalt, overlain by Upper Cretaceous sedimentary rocks, overlain in turn by Lower Tertiary sedimentary rocks (Bowin and Nalwalk, 1963). The serpentinized peridotite has velocities close to 5.1 km/sec and may indicate a compositional variation in the seismically determined 5.1 km/sec layer, or the serpentinized peridotite may be from an exposure of a vertical intrusive.

Acoustic Positioning of Dredge

The acoustic positioning data of the dredgings on the north wall during CHAIN Cruise 34 proves to give the horizontal position of the dredge relative to the ship with an uncertainty of only about 200 meters in water depths of 6 to 7 kilometers. The navigational control of the ship, partly from Loran C and partly by other standard but less adequate methods, is much more uncertain, probably of the order of 3 to 5 kilometers. Since the outcrops were located by the ship in the course of maneuvers for dredging the important uncertainty is the former one, which is small enough to assure that the apparent outcrop was sampled.

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ROCKS DREDGED FROM SEAMOUNTS IN THE WESTERN NORTH ATLANTIC

Robert H. Feden

ATLANTIS Cruise 296 and CHAIN Cruise 36 obtained several good dredge hauls from various seamounts along the eastern coast of the United States.

The ATLANTIC cruise was concerned primarily with the New England seamounts (between 36°00'N and 40°00'N, 63°00'W and 67°30'W). Although most of the rocks recovered were glacial erratics, some autochthanous volcanic rocks and clays were obtained from Pickett Seamount. The volcanic rocks are highly altered; petrographic analyses show them to consist mainly of clay with small, decomposed plagioclase phenocrysts. Nontronite, an iron-rich montmorillonite and a probable alteration product of basalt, was identified by X-ray diffraction techniques. A large phenocryst of clinopyroxene was found in one of the rocks.

During CHAIN Cruise 36, fragments of altered basalt and manganese nodules were dredged from Caryn Peak (36°42'N, 67°59'W).

The basalts contain many plagioclase phenocrysts in a fine-grained, partly glassy groundmass. The plagioclase laths in a few of the specimens have a preferred orientation which indicates flow during crystallization.

In general, the basalts appear to be similar to others dredged from the deep sea. The presence of these basalts strongly suggests a volcanic origin of the seamounts. The absence of a flat top on both Pickett and Caryn makes it doubtful that either of these seamounts were ever at the surface of the sea. However, there is still much conjecture on this point.

ROCKS DREDGED FROM THE BARRACUDA SCARP

Richard L. Chase

The Barracuda Scarp is the steep north slope of a feature best described as a gigantic cuesta or asymmetric ridge which is over one hundred miles long, and trends east-southeast beneath the ocean east of the Greater Antilles. The south slope of the feature is relatively gentle. At its highest point, the crest of the ridge is 3270 meters below sea-level. To the north is a flat plain approximately 5840 meters below sea-level.

A haul of basalt was obtained by drawing a dredge up the scarp at 16°43'N, 58°05'W. The basalt is in angular fragments and is inferred to have come from outcrops on the scarp. Preliminary examination of thin sections of the rocks shows them to be little-altered tholeiitic basalts with plagioclase phenocrysts. The basalts are similar to more altered rocks dredged from the north wall of the Puerto Rico Trench some 900 kilometers to the west-northwest, and to rocks described from the Pacific Ocean by Engel and Engel (1963).

References

Engel, C.G. and A.E.J.Engel, 1963. Basalts dredged from the Northeastern Pacific Ocean. Science 140: 1321-1324.

The following report was inadvertently omitted from the "Summary of Investigations conducted in 1962" (WHOI Ref. No. 63-18) and is now included here.

MAGNETIC PROPERTIES OF OCEANIC ROCKS

John W. Graham

As a consequence of studies made during the past fifteen years, involving hundreds of measurements of the magnetic properties of crustal rocks of the earth, a controversy of major importance in geophysics has developed.

Ardent rock magneticians - and they are numerous and vociferous - would have us believe that their evidence proves that during the geologic past, the important processes of continental drift and polar wandering have taken place. A more conservative school maintains that even though the data, with some notable exceptions, are reasonably consistent with these inferences, more must be learned about the mechanisms by which rocks become magnetized before such conclusions can be accepted. This view of moderation is strongly influenced by other geophysical studies which demonstrate clearly that polar wandering and continental drift are incompatible with our present-day understanding of the dynamic, physical, and chemical properties of the earth.

Oceanic sediment samples have received relatively little attention in these studies because they are generally difficult to obtain and because their weak magnetizations can be measured easily only with exceptionally good magnetometers. During the year we decided to become active in this field and undertook the development of an instrument suitable for making semiautomatic continuous measurement down the oriented core length of samples, of the "fossil" magnetic compass directions that appear to be acquired at, or shortly after, the time the sedimentary material is deposited on the ocean floor. This new instrument employs a number of novel features which have made it possible to achieve both remarkably useful sensitivity (minimum detectable magnetic field less than 10^{-10} gauss) and the desired automatic recording. The following details show how these goals have been accomplished.

An astatic array of magnets is suspended on a stiff fiber which allows a torsional mode of oscillation of the system at about 4 cps. The sample is revolved around a horizontal axis below the suspended system at exactly 4 cps by a synchronous motor whose speed is controlled by a constant-frequency tuning fork. The torsional-oscillation frequency of the suspended system can be

adjusted with great precision by controlling the current through a small Helmholtz coil whose magnetic field acts on one of the magnets of the array. When the frequencies of the suspended system and the revolving samples are synchronous and remain so, the torsional oscillations of the suspended system build up by resonance to a limit which is determined by the radial magnetization component of the sample and the damping acting on the system. It has been found practicable, by this system of resonance, to realize gain in excess of 100 over the static deflection that the nonrotating sample would exert on the magnet system. The oscillations of the suspended system are detected photoelectrically and these signals are processed by circuits patterned after those in common use in spinner magnetometers. A null-seeking servo system is used to control the output of the phase detector; this drives a recorder, so that the desired information on the orientation of the magnetization component is plotted automatically. Phase stability is excellent, and the benefits of long-time integration can be realized when measuring weak samples. Intensity is also recorded automatically. A "lathe" for revolving either a multiple sample holder of a 10-foot length of core and traversing it below the magnetometer at any chosen height has been fabricated and is about ready for test. With this lathe it will be possible both to examine a length of core continuously, and thereafter it will be used to process individual samples cut from selected portions of the core.

It is expected that this magnetometer will eliminate much of the tedium that is involved in making large numbers of measurements of weakly magnetized samples, and it is hoped that its great sensitivity will make possible the study of a host of samples that previously have not been measurable, or not measurable after partial demagnetization.

THE FREQUENCY DISTRIBUTION OF SOME CHARACTERISTICS OF BOTTOM TOPOGRAPHY

Joseph W. Mizula

Quantitative analysis of ocean bottom topography was extended to more and smaller sub-divisions of two transatlantic profiles (Long Island - Bermuda - Gibraltar and Long Island - Bermuda - northern Britain). Such analyses, in general, have two major aims. The first, purely descriptive, is directed toward an objective quantitative description of variousj aspects of submarine topography, such as slope, slope length, curvature, and depth.

This would serve as the basis for comparing different parts of the ocean, and would ultimately lead to a quantitative, physiographic classification of the ocean bottom.

The second aim which follows logically from the first, has a dual purpose. The descriptive information should be applied, insofar as this is possible, to the interpretation of cause and effect in the evolution of various types of bottom topography. Secondly, numerical description of bottom topography should be of practical use in certain engineering applications where the configuration of the ocean bottom is of immediate concern.

The present analysis has shown that a log-normal frequency distribution function appears to fit the data for slopes, slope lengths, and curvatures or rates of change of slope. That is, the logarithms of these variables appear to be normally distributed. The distribution of depth, on the other hand, appears to be normally distributed. If a definite frequency distribution function can be derived for certain topographic variables and a physical basis for it found, then it should lead to a clearer understanding of the operation of geomorphic processes.

There is a well-defined, positive correlation between average slopes and average curvatures (rates of change of slope in degrees per mile) for the different types of topography that were studied. This is perhaps not too surprising, for it might be expected that areas having steep slopes would also have a greater rate of change of slope than areas with low slopes. What is surprising, however, is that in the distribution of average curvatures there is a pronounced gap near the center of the distribution where almost no values occur. Figure 1 is the distribution of average bottom curvatures for the 90 sections of the profile that were studied. Since curvature is a function of the steepness and length of adjacent slopes, the relationship between slope and slope length was examined for explaining the gap in the distribution. There is a negative correlation between slopes and slope lengths for those sections having average slopes of 0.3 degrees or less. For those sections having average slopes slightly greater than 0.3 degrees, the average slope length decreases abruptly from about 0.6 miles to 0.3 miles. There appears to be no correlation between average slope and slope length for those sections having average slopes greater than 0.3 degrees. The explanation may be that the sections having curvatures less than about 0.7 degrees per mile represent those portions of the profile where sedimentation has largely modified the original topography (which generally appears to be the case). This would raise the question as to why there are not transitional sections where sedimentation is taking place but has not yet greatly altered the original topography.

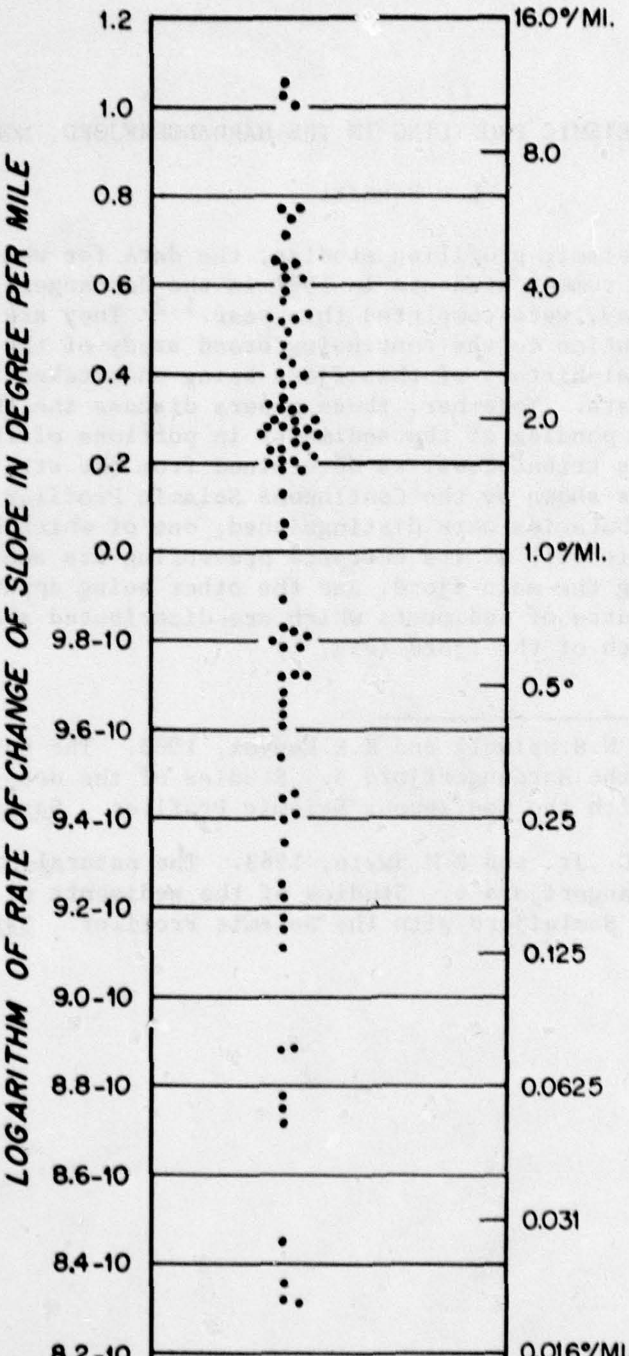

FIGURE 1. DISTRIBUTION OF AVERAGE BOTTOM CURVATURES. EACH POINT REPRESENTS THE AVERAGE RATE OF CHANGE OF SLOPE FOR A PORTION OF A TRANS-ATLANTIC BOTTOM PROFILE.

CONTINUOUS SEISMIC PROFILING IN THE HARDANGERFJORD, NORWAY

Lee Bennett

Two seismic profiling studies, the data for which were collected by summer students in 1960 in the Hardangerfjord, western Norway, were completed this year.[1,2] They are published as a contribution to the continuing broad study of the geological and biological history of this fjord being undertaken by Norwegian scientists. Together, these papers discuss the thickness, sources, and ponding of the sediments in portions of the main fjord and its tributaries, as determined from the stratigraphic relationships shown by the Continuous Seismic Profiler. Two types of tributaries were distinguished, one of which has a characteristic sill at its entrance preventing its sediments from entering the main fjord, and the other being apparently an active source of sediments which are distributed along the central trench of the fjord (Fig. 1).

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[1]Cone, R.A., N.S.Neidell and K.E.Kenyon, 1963. The natural history of the Hardangerfjord 5. Studies of the deep-water sediments with the Continuous Seismic Profiler. Sarsia 14:61-78.

[2]Bennett, L.C.,Jr. and S.M.Savin, 1963. The natural history of the Hardangerfjord 6. Studies of the sediments of parts of the Yter Samlafjord with the Seismic Profiler. Sarsia 14: 79-94.

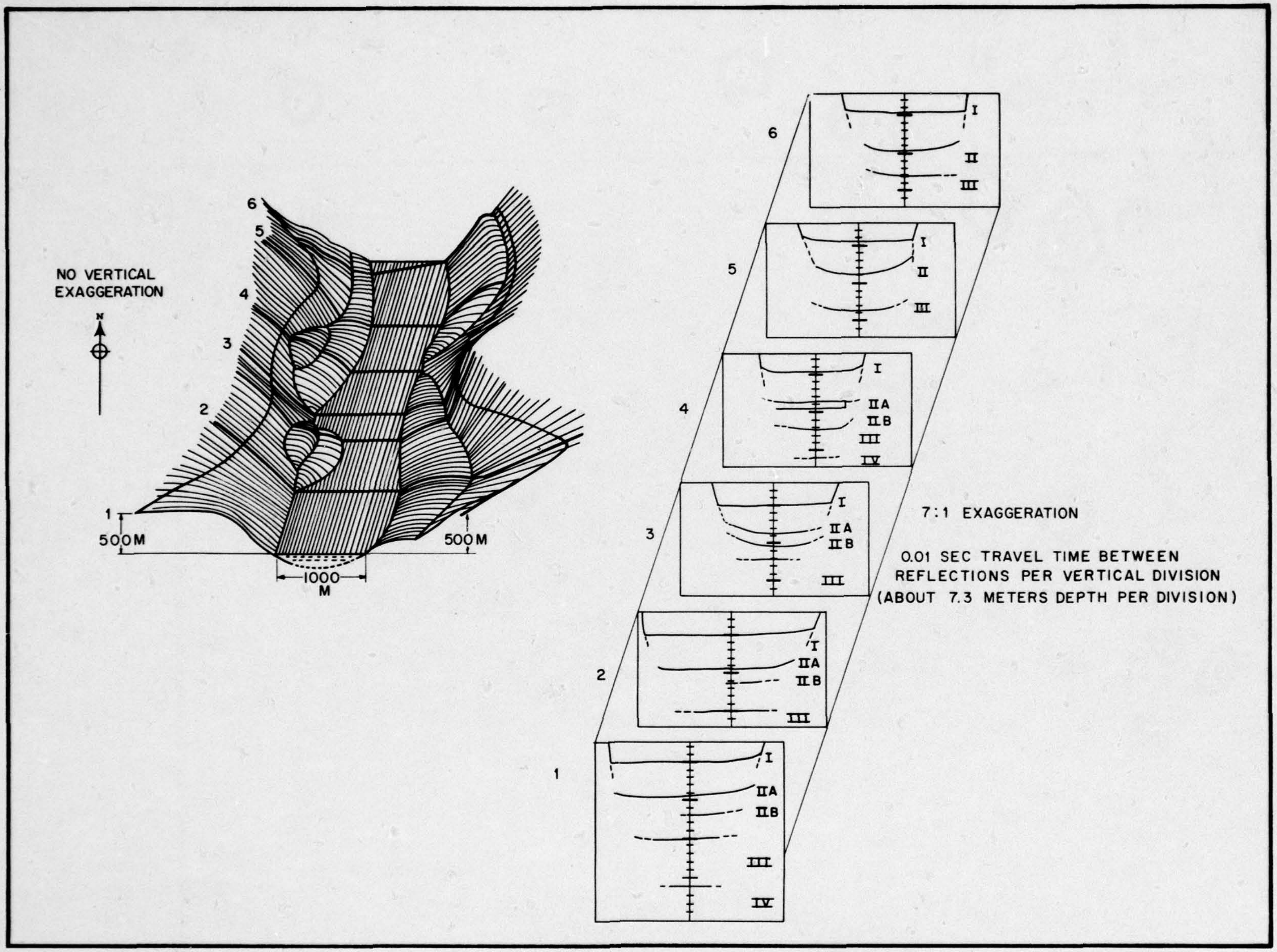

FIGURE 1. RECONSTRUCTION OF THE BOTTOM AND SUB-BOTTOM STRATA OF PART OF THE SAMLOFJORD, NORWAY. FIGURE ADAPTED FROM CONE et al (1963).

ACOUSTICAL AND OCEANOGRAPHIC INSTRUMENTATION

SEISMIC SIGNAL PROCESSING TECHNIQUES

David D. C.ulfield and Richard T. Nowak

Investigation during the last year of the frequency spectrum of the sparker pulse, and of bottom and sub-bottom returns has lead to the development of a matched-filter detection system for improving the signal-to-noise ratio of the receiving system by a factor of about eight to one. This results in greater penetration, and improvement in resolution.

The present system is designed for maximum penetration rather than for highest resolution, since it operates in the range from 15 to 150 cps. Models with a frequency response up to 300 cps are now being constructed to increase resolution. These systems obtain the cross-correlation function of the returning signal with an approximate model of the outgoing signal and discriminates against signals that do not have the same frequency components and phase relationships as the initial outgoing signal.

The output of the correlator is basically the convolution integral of the incoming signal with a model of the outgoing signal after it has passed through a band-pass filter similar to that used in the receiver. The output signal is squared and sent to a signal-level discriminator. The output of the discriminator is amplified and displayed on a Precision Graphic Recorder. Figure 1 shows the correlator being used to clarify the complex structure near a submarine canyon. Each dark line in the left side of the figure represents a major or seismic reflector. It is hard to identify these layers on records made with the older method (right side of figure). A typical record (Figure 2) shows the dark lines of the major acoustic reflectors. The width of the dark band is determined approximately by the time duration of one-half wavelength of the lowest frequency studied. This record was made southeast of Martha's Vineyard. Maximum penetration is more than twice that obtained with conventional passive filters.

The energy of the output of the correlator is directly proportional to the actual energy in the returning signal. Hence, a means is opened up of measuring with greater accuracy the energy contained in each sub-bottom reflection. Also, varying the parameters of the matched filter may enable one to obtain the characteristic transfer function of a given sub-bottom layer. This would provide more information about the actual structure of the sub-bottom.

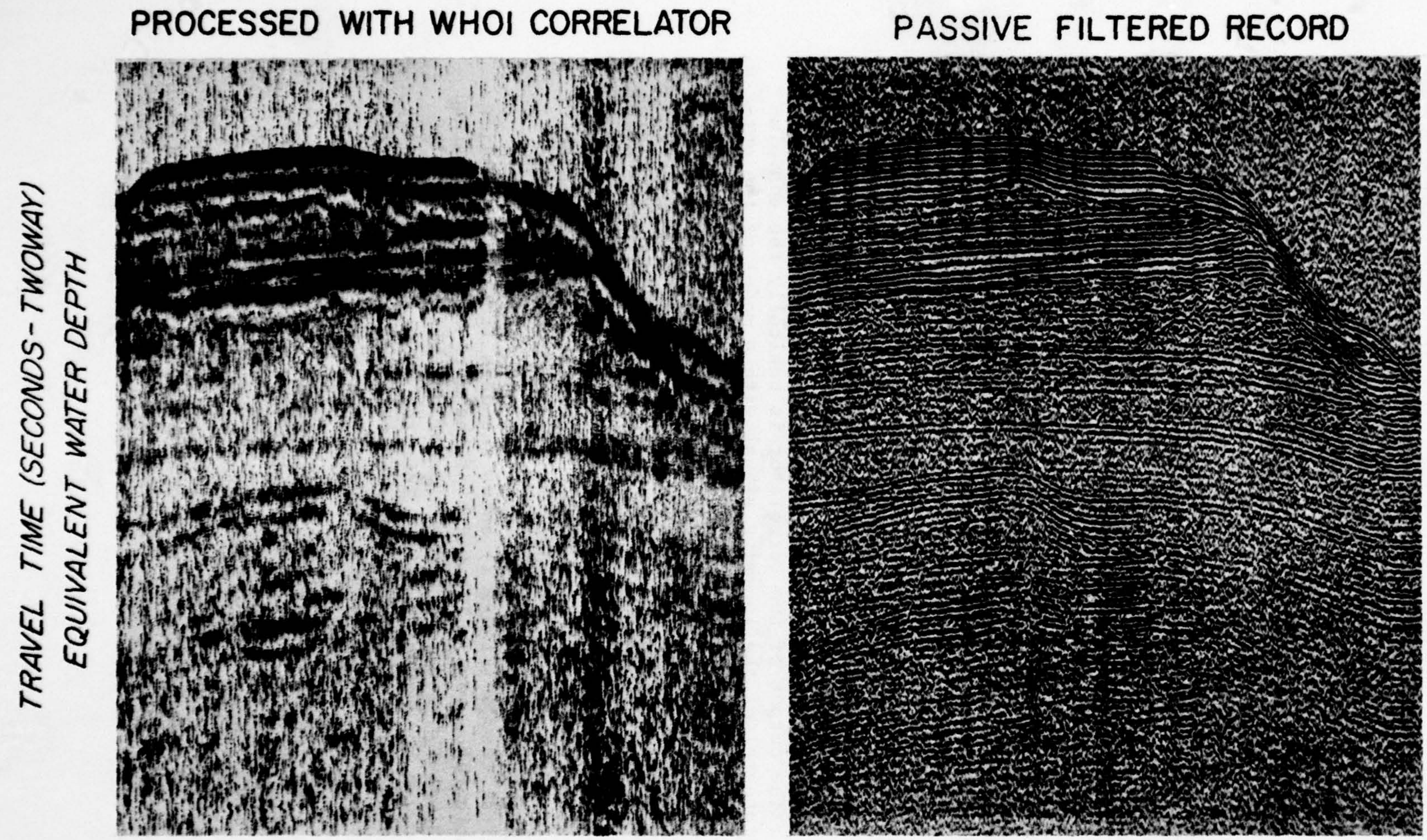

FIGURE 1. COMPARISON OF CORRELATED AND STANDARD PG RECORDS.

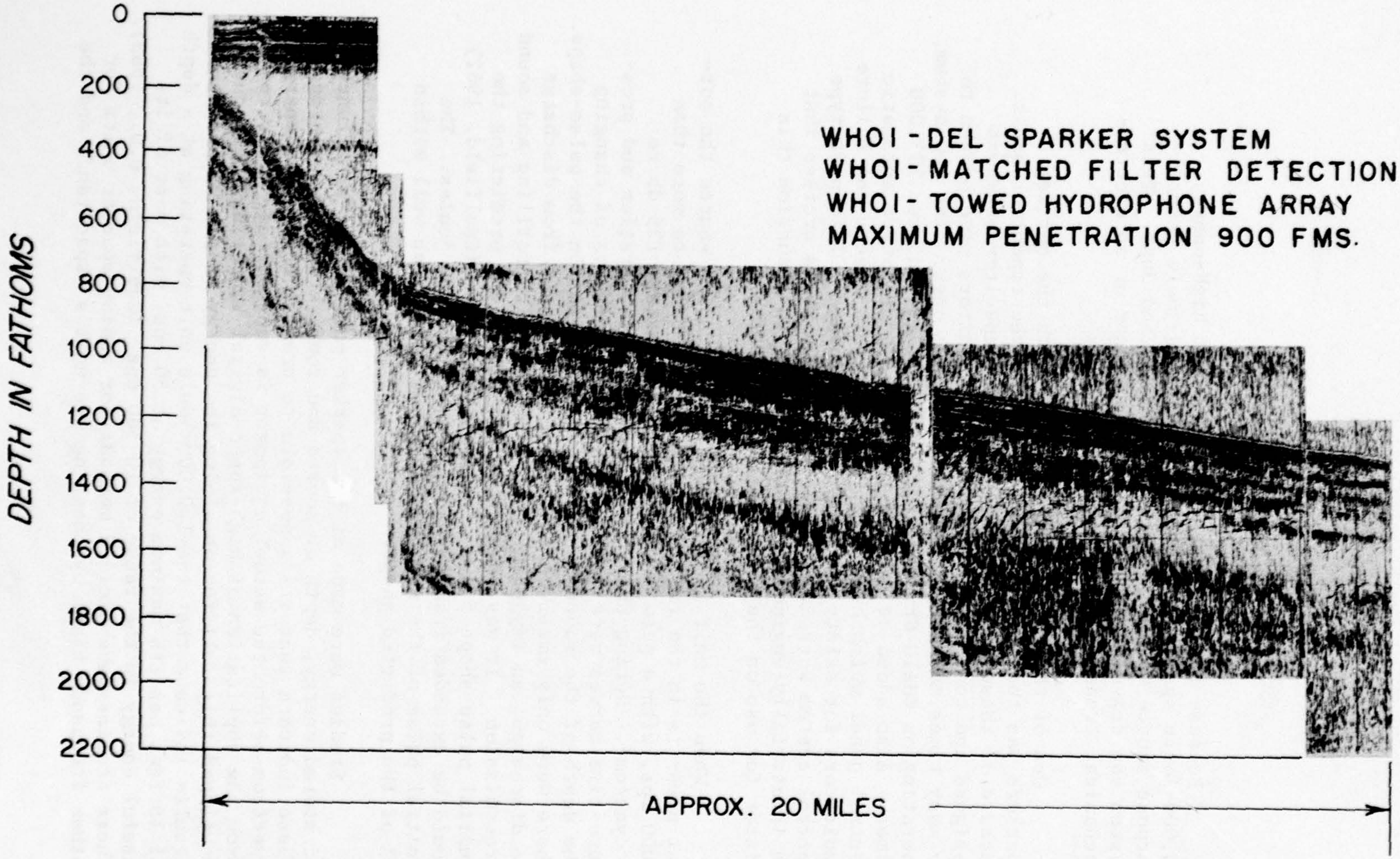

FIGURE 2. PGR RECORD OF MATCHED FILTER DETECTION SYSTEM USED IN SEISMIC SIGNAL PROCESSING.

SPARK SOUND SOURCES

David D. Caulfield

Because of the success of the first high-energy 25,000-joule spark sound source, a 100,000-joule general-purpose source was constructed during May and June. This system can drive either a sparker transducer or an electromechanical transducer.

One of the primary difficulties with the earlier sparkers was the catastrophic failure of the capacitor banks. Because of these failures a new type of capacitor bank was designed and constructed. These new capacitors have proven to be many times more reliable than the older ones. The new system, operating on CHAIN Cruises 37, 38 and 39, cycled over 133,000 times. Also added to the new system was a prototype automatic control panel which has a complete interlock system and failure indicators for safety and ease of maintenance. This prototype control system worked so well on the above CHAIN cruises that an industrially-engineered model is under construction this winter for use on the Indian Ocean Expedition.

When the unit is used as a sparker sound source the output power is in the frequency range from 10 cps to more than 1000 cps, with a peak pressure of approximately 135 db re 1 dyne/cm^2. During CHAIN Cruise 39, many calibration and pressure-time curves were made to analyze the effects of changing the depth of the source and operating energies on the pulse-shape. There were only small variations of pulse-shape from discharge to discharge, an important factor for seismic profiling and sound transmission. It was found that the theory for predicting the initial pulse-shape for a given sparker system (Caulfield, 1962) could be extended from 25,000 joules to 100,000 joules. The initial pulse of the new 100,000-joule source was well within 5% of the predicted shape.

Studies were made of the sparker pulse-shape as a function of stored energy, depth of source and configuration of source. These indicate that it is possible to predict the entire energy spectrum before the actual equipment is constructed. This results from the application of high-speed digital computing techniques developed this fall for obtaining the energy or power spectrum. Results indicate that the 100,000-joule unit operating at a depth of 15 feet has its maximum energy at 50 cps, with most of its useful energy in the range of 10-500 cps (Caulfield, D.D., 1963). These studies have yielded methods for tuning sparker units for other frequency bands by changing the unit's capacitance and the

operating depth of the electrode. Two of the most important characteristics of the sparker pulse are the bubble-pulse interval and the peak pressure. The bubble-pulse interval behaves as it does in underwater explosions. The peak pressure of the initial sparker pulse, for a given operating energy, remains constant with depth. The bubble-pulse interval is proportional to the depth in feet raised to 5/6 power and the stored energy raised to the 1/3 power. Detailed knowledge of the energy spectrum for given operating conditions in the field have further increased the ability to obtain better seismic profiling records.

Spark electrodes have been a major problem in sparker design. During the year a continuing study of various materials and consideration of lifetime-versus-acoustic output and cost has led to the conclusion that brass makes the best electrode. This summer electrode lifetimes of up to 37,000 discharges were obtained at discharge repetition rates of 1 spark per 10 seconds. Present mechanical design of the electrode allows for changing it in one-half hour or less by experienced personnel. Another finding resulting from electrode research is that, except for the diameter of the electrodes, the size of the entire spark transducer may be made the same for all energy inputs from 1,000 to 100,000 joules. This is an important consideration in handling at sea.

References

Caulfield, David D. 1962. Predicting Sonic Pulse Shapes in Underwater Spark Discharges. Deep-Sea Res. 9:339-348.

Caulfield, D. D. (in press). Pulse Shape Analysis and Seismic Data from the New 100,000-Joule Sparker Source. J.Underwater Acoustics.

HYDROPHONE ARRAYS AND THE FIVE-CHANNEL SUITCASE

Willard Dow, Hartley Hoskins, and R. T. Nowak

In seeking a better signal-to-noise ratio in seismic reflection profiling, advantage can be taken of the fact that the energy reflected from the sea floor back to source travels nearly vertically. A directional receiver oriented vertically discriminates against much of the other sound generated by the towing ship and by water waves. A simple array that can be readily streamed consists of a series of elements placed in tandem, i.e., a "line array".

The resulting directionality of "lobe" pattern is cylindrically symmetric and discriminates against ship-generated sound. Depending on the spacing of detectors and the manner in which the signals from each detector are combined, the array may be made quite directional over the range of an octave or more. By combining the separately-recorded outputs of each element with a variety of delays so as to effectively vary the dimension and orientation of the array, the coordinate process of "velocity filtering" extends the usefulness of the array.

For reflection profiling, the receiving array and a Sparker or Boomer sound-source are towed over the area of interest, the active portion of the line being dragged at the end of 1,000 feet of special neutrally-buoyant cable. The active sections of our current line arrays were built, and later modified, to our specifications by Chesapeake Instrument Corporation. They contain five pairs of transmitting and receiving elements mounted 12 feet apart in a neutrally-buoyant 50-foot reinforced rubber hose. The transmitting elements can be pulsed and the surface echo detected by the receiving units, thus providing a continuous depth record of all parts of the array whenever required.

The commercially-built hydrophone arrays have been unsatisfactory in certain structural and electrical respects, although some excellent seismic profiling records have been taken with them over the past year. The arrays are therefore being modified and rebuilt at Woods Hole. New double-Darlington complimentary-symmetry transistor preamplifiers are also being constructed for them on a trial basis.

A new 5-channel suitcase in compact modular form is being constructed by Carleton Grant, Jr. It is designed to work either with arrays or individual hydrophones. The towing assembly consists of a depressor, towed by a faired pendant from which is streamed 900 feet of neutrally-buoyant 20-conductor cable terminating in the electronics housing at the head of the array. We have experimented with various types of cable construction in an attempt to improve towing characteristics, thereby minimizing background noise.

DEEP-ANCHORED ACOUSTIC BUOY NAVIGATION SYSTEM

Willard Dow

One of the major difficulties encountered during the THRESHER search was the pin-point navigation required to follow precisely a search grid of the area. The best positions from electronic navigation were reliable at best to one-eighth of a mile and even taut-wire navigation buoys could move as much as a mile when anchored in 8500 feet of water. It was therefore decided to try anchoring an acoustic buoy with a hydrophone buoyed 600 feet above the bottom to restrict lateral movement of the reference. The survey ship would then range to this deep hydrophone using a Sparker or Boomer as a pulsed sound source. The pulses thus received were amplified by the hydrophone preamplifier and transmitted via a single-conductor well-logging cable to the surface buoy which in turn radioed the signals back to the ship. As the interval between transmitted and received pulses were then essentially ship-to-hydrophone acoustic travel times through the water, ranges to the hydrophone could be readily determined.

The buoy system was assembled at WHOI by Messrs. Carter, Grant, and Stillman with the assistance of the Oceanographic Research and Equipment Company. The buoys were anchored by means of the 1/4"-logging cable near the THRESHER area during CHAIN Cruise 38 (4-17 August 1963).

The system operated successfully for about 11 hours but operations had to be terminated at a range of six miles because the marker buoy had dragged the light anchor into deep water. The experiment demonstrated, however, that the system has the capability of providing precision navigation over small geographical areas in deep water. During the run oblique reflections from sub-bottom layers were also detected, indicating that the system has potential for seismic measurements as well.

HIGH-POWER, SHORT-PULSE ECHO-SOUNDER

Willard Dow

The transmitter of the high-power, short-pulse echo-sounder has a 12-kcps circuit similar to that used in the Inverted Echo Sounder, but is capable of full-power operation at repetition rates up to 10 pulses/second. This unit, developed with the cooperation of the Del Electronics Corporation, is designed for shipboard operation utilizing the UQN transducers in the ship's hull.

The instrument proved useful in the THRESHER search as a means of providing fine-line delineation on the PGR record of individual echo sequences appearing simultaneously and often intersecting. Echo sequences which do not join the rest of the apparent bottom trace in a normal fashion could be indicative of a large object projecting from or lying on the bottom. The normal long-pulse echo-sounder tends to blend these individual echo sequences into a single, broad bottom return. If the pulse is shortened without maintaining, or increasing, the peak power in the pulse, the individual profiles may become obscured in background noise. It is for these reasons that the high-power, short-pulse transmitter was developed. A wide-band, low-noise receiver is also required, an experimental model of which has been constructed at WHOI and is being tested.

DEEP TOWED VEHICLE

Willard Dow

The period from 11 April to 27 May was almost completely devoted to preparing equipment for the THRESHER search and in operating this gear at sea. Through the intensive efforts of Stephen Stillman, Alexander Johnston, Carl Grant and others, a vehicle designed for deep towing was assembled on a crash basis in about two days' time. On this vehicle were mounted stereo cameras with strobe lights to illuminate the bottom for photography.

An Inverted Echo Sounder (see WHOI Ref. No. 63-18, pp.24-25) was mounted on its side in the nose of the vehicle to act as an echo ranger. This might serve to guide the cameras to any likely targets on bottom.

A Schlumberger potential device was included in the assembly to help determine whether any such targets contained dissimilar metals.

The vehicle was towed from the A-frame of ATLANTIS II throughout the search by means of a multi-conductor oil well logging cable. In spite of difficulties in locating and navigating the vehicle close to the bottom in 8500 feet of water, the combination in one unit of an echo ranger for survey and cameras for identification eventually proved a valuable aid to the search. For example, the debris believed to have come from the THRESHER was first photographed after receiving a series of echoes which clearly suggested a number of small objects strewn across an otherwise featureless bottom area. These echoes, of course, could not be uniquely identified with the debris, but they do provide corroborative evidence suggesting that even small objects such as these can be located by this means. This experience is in accord with earlier experiences where similarly recorded echoes accompanied photographs of cobbles and small boulders sitting on the bottom.

Although the vehicle was finally lost at the beginning of our last cruise to the THRESHER area, its overall performance had indicated that with suitable modifications it could have been made a valuable tool for general bottom survey, and for other applications such as locating and photographing scattering layers from the horizontal aspect. Therefore an improved version of the vehicle is planned for the near future.

GEOGRAPHICAL LOCATION OF DEEP-SEA TOWED INSTRUMENTS

Lincoln Baxter II

To survey the bottom of a given deep-sea area with a camera, or other instrument towed near the bottom, one needs to know continually and precisely the geographical location of the instrument. In many areas the position of the towing ship may be determined to within a few hundred feet or better with electronic systems like Raydist, Decca, Loran C, or by radar ranges from tautline-anchored buoys. The location of a deep-towed instrument frequently differs from that of the towing ship by a half-mile or more. In the course of our participation in the search for the wreckage of the submarine, THRESHER, we reduced to practice a sonic-location system which, during the search, permitted us to locate the towed instrument with respect to the ship considerably more accurately than we could locate the ship.

A detailed description of the method, with equations for determining instrument range and bearing from any configuration

of three shipborne hydrophones, will be published (Baxter 1964).

Reference

Baxter, Lincoln, II. 1964. A method for determining the geophysical position of deep-towed instruments. Deep-Sea Res. (in press).

SHIPBOARD DATA-PROCESSING SYSTEM

Carl O. Bowin

An automatic sea gravity system utilizing a digital computer was designed and developed during 1962 in an effort to reduce the time required to bring together the pertinent information for the computation of gravity values, to reduce the time required for the computations themselves, and to make the results available for interpretation, planning, and checking purposes aboard ship while the cruise is in progress. Following the successful development and operation of this first shipboard computer system, it was proposed to improve and expand the initial system along the following lines: introduce control capability, increase the number and variety of inputs, provide for on-line plotting, improve the input-output capability of the computer, and add a logging system to provide a means of storing all data then recorded in various notebooks, log sheets, etc., both in the bridge and in the laboratories.

Ideas for the improvement and expansion of this system were discussed in renewed negotiations with International Business Machines Corporation. System II, which has resulted from these negotiations, is the product of many people's creative contributions blended together to yield a very powerful and versatile computer installation. System II automatically samples, computes, and records values of ship's heading and speed, latitude and longitude, water depth in fathoms and meters both corrected and uncorrected for variations in sound velocity, gravity in terms of total acceleration, and free air and Bouguer anomalies, and the magnetic field of the earth. All of these values are automatically identified with date and time in both local ship's time and Greenwich Mean Time.

The basic computer of the new system has remained an IBM 1710 control system, which includes a 1620 digital computer with 60,000 memory core storage, a 1711 data converter, and now, additionally, a 1712 multiplexer and terminal unit. The 1712 gives

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the computer control capability which permits feedback of information from the computer to various members of the sensing input units and permits the operation of remote displays and alarms. Input-output capability now includes a 1620 console typewriter, 3 buffered remote input-output typewriters, a paper-tape reader and punch, a card reader and punch, and 3 magnetic-disk storage drive units.

The single most exciting advance made possible by the new system is the utilization of the magnetic-disk storage units. These offer very rapid input and output of data combined with the advantage of random access storage. In addition, the magnetic disks are removable, thus allowing interchange of disk packs when either a pack is full of data or new problems are to be solved by the computer system. Each pack is able to store 2,000,000 digits, equivalent to data collected by CHAIN during two-thirds of a month at sea. These disk units allow a further significant development, namely, the merging of real-time, on-line computations with background off-line computations. Several major difficulties have been encountered in effecting this time-sharing capability but they appear to be surmountable. Once in operation, this capability will allow us to compile, and then run, new programs written in symbolic or fortran language while real-time data is continuously being collected automatically and processed by the same computer. Also aboard the CHAIN is a key punch with a typewriter connected to it, thus making it possible to originate a program at sea, punch the program cards, compile the program, run the compiled program, and then list the output cards without interrupting the basic real-time operations of the shipboard data-processing system.

Three remote input/output typewriters are being used in experiments to improve the collection, dissemination, and availability of the scientific and navigational information logged during the course of a cruise. Previously, this information was recorded in a variety of notebooks and data sheets in the top and main laboratories and on the bridge of CHAIN. In the new system, a typewriter installed at each location replaces the notebooks. When an item is typed on one of the typewriters, the same message is immediately typed remotely by the other two and is also recorded on a magnetic disk unit where it is available for listing or searching of the logged information.

New remote computer-controlled counter units display the computed dead reckoning position on the bridge and on the top and main laboratories. These counters are updated automatically every minute. Another computer-controlled display unit consists of four

nixie lights which display the numerical contents of any core location in the computer memory. Thus ship's speed, ship's heading, free air anomaly, Bouguer anomaly, uncorrected water depth in fathoms, corrected water depth in fathoms or meters, magnetic values, or any selected computer value may be displayed and observed in the main or top laboratory without interrupting the normal computer operations. This facility has proved very useful for checking, testing, calibration, and informational purposes.

It is hoped that this incomplete discussion may indicate, at least to some extent, the scope and flexibility of our existing shipboard data processing system.

BATHYMETRY AND THE SHIPBOARD DIGITAL COMPUTER

Sydney T. Knott

Echo-sounding inputs to the IBM 1710 Digital Computer aboard R/V CHAIN were needed last year for the computation of the free air anomaly of gravity. Yet this is but a first step toward full employment of sounding for interpreting bottom topography in geological terms while at sea (see, for instance, Mizula, and Breslau and Hersey, pp. 143 and 110).

At the present state of development, only the digitization of first arrival time measurements are automated. To do this, discriminating circuitry has been devised to assure that the measurement is made from the leading edge of a bottom echo rather than noise spikes, scattering-layer echoes, and similar interferences. Unwanted signals are gated out, required signals, let in. A digital output counter provides input information to the IBM 1710 control system. Further programmed gating makes the information available at prescribed times.

Logical extensions of this technique can be made directly to all travel-time measurements in hydroacoustics where the wave train has an abrupt beginning against a background of ambient noise. Currently, a signal-to-noise voltage ratio of about 6-8 db is needed for reliable operation.

A next step in extending this technique is being made by R. Nowak and others by feeding the travel times from the inverted echo sounder, which is an integral part of our velocimeter system, into the computer. The velocity profile can quickly be computed from this information and subsequent inputs from the velocimeter.

SPECIAL PROJECTS

THE SEARCH FOR THRESHER

J. B. Hersey

Participation by WHOI staff in the search for the THRESHER has been described previously in some detail (Hersey, 1963) and four papers are currently in press on special navigational methods, echo-ranging near the sea floor, and the use of photomosaics as a search technique. These papers and others will be published in the near future. One note on navigational techniques by L. Baxter appears in this summary.

It is difficult to report in scientific and technical papers the response of a whole institution to a national emergency of this sort. From the time of the decision soon after THRESHER was lost in mid-April until now, a considerable portion of our staff have devoted full time either to search, analysis of data from the search, or to various discussions or researches into means of dealing more effectively with such a disaster in the future.

Mr. S. T. Knott ably took charge of most of the search operation from ATLANTIS II. Of the many people who assisted him, Mr. Dow and Mr. Stillman for acoustical and mechanical problems, Mr. Johnston for photographic problems, Mr. Hess for a variety of electronic problems, and Mr. Max Silverman (of Scripps Institution of Oceanography) for navigational plotting contributed very heavily.

The biologists made critically important contributions at an early stage under the leadership of Nathaniel Corwin, Dr. Hays, Chairman of the Applied Oceanography Department, and others from various departments volunteered their services on ATLANTIS II or on naval ships. Mr. Allyn Vine headed a team of analysts of topography and other search data reaching the R/V MISSION CAPISTRANO from various vessels during the mid-portions of the search in May. Mr. Vine's other contributions are detailed below.

Analysis of the photographs taken of the sea floor during the search continues today. These can generally be fitted together to form long photomosaics which can be fitted together to tell us much about the geology of the disaster area and perhaps will bring us fundamentally new insights about the disaster itself.

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SUBMERSIBLE VEHICLES

Allyn C. Vine

From May to December the author spent a majority of his time working as a science advisor to Admiral Stephan of the newly-appointed Deep Submerged Systems Review Group. This group was set up by the Secretary of the Navy to make recommendations as to what the Navy could do to improve their capabilities for finding sunken submarines, rescuing personnel, and recovering the submarine if required. In view of the worthwhile national objectives and the group's need for oceanographic information, several oceanographers around the country spent part time with the group.

The DSSRG was made up of a small group of full-time Navy and civilian staff with many part-time individuals from industrial, scientific laboratories, and government offices. Oceanographic factors of great interest to the group were: bottom currents, bottom visibility, firmness of the bottom, and a wide variety of oceanographic instruments. If the group's recommendations are carried out there should be engineered many tools and equipment which would directly or indirectly assist oceanographers in their research programs. Another likely result of the DSSRG report is that it will draw attention to the need for oceanographic engineers in addition to oceanographic scientists. The author's participation in this work was supported by Contract Nonr-4029(00) with the Office of Naval Research.

The author provided consultation to the Deep Submersible Group of the Applied Oceanography Department on instruments and navigational techniques for the Woods Hole research submersible. In addition he visited Cmd. Houot at Toulon, France to discuss operational and scientific problems and details for the planned dives of the French bathyscaphe ARCHIMEDE in the Puerto Rico Trench in the spring of 1964. A scientific problem of particular interest is the observing, photographing, and collecting of rock from the outcrops of the north wall of the Trench which has been explored previously (Hersey, Nalwalk, and Bowin, 1963).

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PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Frederick C. Fuglister, Department Chairman

DEEP CURRENT OBSERVATIONS

Joseph R. Barrett

Investigations into the nature of deep currents in the western Atlantic have continued this year. The first part of the year was spent in analysis of deep current measurements made the previous year off Cape Hatteras. This work is now nearly completed.

During July and August two short cruises were made as part of the summer student training program in Physical Oceanography. On the first cruise an oceanographic section of ten stations was made crossing the Gulf Stream south of Cape Cod. Near the southern end of the section, close to the southern edge of the Gulf Stream two neutrally-buoyant floats and a parachute drogue were tracked for two to three days. Additional oceanographic stations were made in order to develop the density field in the near vicinity of the floats. The second cruise continued in much the same vein. A square grid of nine stations was occupied near the southern edge of the Gulf Stream. Stations were spaced about 15 miles apart along both axes and oriented as nearly as possible with one axis parallel to the direction of the surface current. Two neutrally-buoyant floats were released near the center of the grid and followed for three days.

During the late summer preparations were also being made for a cruise of the R/V CRAWFORD in October-November for the purpose of observing water mass properties and measuring deep currents north of the Blake Outer Ridge. The current measurements were severely hampered by rough weather but the oceanographic observation program was satisfactorily completed. These data are now undergoing processing and analysis.

PRESSURE EFFECT ON THE ELECTRICAL CONDUCTIVITY OF SEA WATER

Alvin L. Bradshaw

The investigation of the effect of pressure on the specific conductance of sea water was completed in 1963 and a paper on the work, which will be submitted for publication, has been written. In brief, the percentage increase in specific conductance was measured over the pressure range 0 to 15,000 lbs per in^2 gauge (equivalent to about 10,000 meters in depth) for sea waters of 31, 35 and 39^o/oo salinity at temperatures of 0, 5, 10, 15, 20 and 25^{o}C. This covers the ranges of interest of these variables in the oceans. The accuracy of the results is estimated to be equivalent to better than $\pm$ 0.01 ^{o}/oo salinity units.

A joint paper with Oregon State University on "The Effect of Carbon Dioxide on the Specific Conductance of Sea Water" will be submitted for publication. In it, measurements of the changes in specific conductance associated with changes in the distribution of the components of the carbon dioxide system in sea water are presented.

DIRECT CURRENT MEASUREMENTS

John G. Bruce

In February and March 1963 a joint cruise was made using two ships in the Tongue of the Ocean and the Northeast Providence Channel region to study the general water circulation. Four areas were selected for measurements, the first being at the Northeast Providence Channel eastern entrance into the Ocean to examine water movement that might influence motion in the Tongue of the Ocean. The remaining three areas were each successively further SW into the Tongue of the Ocean. Drogue measurements were made from 10 meters to 1,500 meters in depth. Prevailing northeasterly and easterly wind seemed to have a large effect on the flow into the channel in the upper 200 meters producing speeds over 50 cm/sec. In no case during the cruise was a steady circulation found, but a somewhat turbulent motion of water down to 1,500 meters seemed to prevail, being in continuous motion with speeds generally less than 40 cm/sec. A flow at 200 m was found to move steadily for nearly two days parallel to the edge of the bank region south of New Providence Island. A similar flow was found in the same location in 1962.

Current measurements were made in the northwestern Indian Ocean from ATLANTIS II during September and October 1963. Direct measurements were made on the edge of the north-flowing Somali Current and at several locations between north-eastern Madagascar and the Seychelles Islands where the South Equatorial Current passes, becoming a source for the Somali Current.

COASTAL OCEANOGRAPHY

Dean F. Bumpus

A program has been conducted on the continental shelf concerned with the circulation and the annual cycle of temperature and salinity since 1955. Presently, this is being supported by contracts with the Bureau of Commercial Fisheries, and the Atomic Energy Commission. The main features were described in the previous "Summary of Investigations".

Mr. Chase has reported the findings of the Oceanographic-Observation Post program under that heading (below).

The drift bottle program has revealed during the past three years a reversal in the direction of the non-tidal drift off the South Atlantic States. There is a northerly drift during March through May, a transition during June, a southerly drift during July through November and an apparent offshore component (no recoveries) until March.

The material for the folio atlas on non-tidal drift on the continental shelf from Cabot Strait to Florida is 5/12ths complete.

The sea bed drifter program is yielding a higher percentage of returns that anticipated with good returns during the winter when drift-bottle recoveries are limited. This is due to the year-round toward-shore drift along the bottom which tends to reinforce the concept of the estuarine character of the continental shelf.

The efforts with moored current meters and thermographs on the continental shelf have not been as productive as anticipated. Instrumental, mooring and read-out problems have severely slowed this part of the program. No satisfactory analyses of data have been completed except for some of the material from off Cape Canaveral

where results of drift bottles, sea bed drifters, moored current meters and drogued telemetering buoys all give consistent results. During March and April there was a predominantly northerly non-tidal drift of approximately 12 cm/sec and during August a southerly drift of approximately 4-5 cm/sec. During March and April the direction of drift was closely associated with the wind direction. When the wind sprung up from the south the current quickly turned northerly. When it hauled to the north it took a large fraction of a day to reverse. During August the relationship with the wind (normally lighter at this time than during the spring) was not obvious.

OCEANOGRAPHIC OBSERVATION POSTS

Joseph Chase

The bathythermograph data collected in 1961 at lightships along the east coast of the United States (Chase 1964) plainly reflect in three cases, the influence of the atmosphere on the shelf water.

Air temperatures which were much below normal along the coast in January and early February were matched by low surface water temperatures in winter (especially in February) and spring at most of the observation posts.

At the lightships from New York to Virginia, the raising and lowering of the thermocline in response to on- and off-shore wind (Chase 1959) occurred repeatedly through the summer. It is hoped that a quantitative analysis of this response may become possible with the collection of more data and that the relationship may prove useful to fisheries investigations.

The fall overturn took place within 11 days at all of the lightships from South Carolina to New York. The events associated with the overturn include the cooling of the surface water with the arrival at the coast of a cold polar air mass in the wake of hurricane Carla, the thickening of the mixed layer in response to a broad field of northeasterly winds and the mixing of the entire water column with the passage of hurricane Esther (Chase 1964).

The report for 1961 is in press and those for 1962 and 1963 are being prepared for publication.

A comparison has been made of the surface temperature records at the lightships with air and water temperatures at locations along the coast (Bumpus and Chase 1964).

Among the results of the analysis are the following:

In recent times surface water temperatures at lightships off the United States east coast have in general followed the trends in air temperature along the coast.

Most of the climatic change in both air and water temperatures has taken place in the winter months rather than in the summer months.

Two peaks in winter temperature in about 1931 and 1950 are apparent in all the coastal air temperatures studied and in the water temperatures at the lightships (except Diamond Shoals) within the limits of the available data. A general downward trend is apparent in more recent winter data.

References

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DIRECT CURRENT MEASUREMENTS IN THE SARGASSO SEA

C. Godfrey Day

A program of direct current measurements using Richardson current meters beneath moored buoys was attempted in the Sargasso Sea. Mooring failure resulted in the loss of much of the equipment, but the records from two of the meters recovered proved enlightening.

The instruments were set at depths of 50 and 100 meters at a point some 250 miles south of Bermuda. This region is thought to be characterized by a slow, westerly, wind-driven circulation of the surface waters. Both current meters, however, showed an unsuspected anticyclonic motion with 24-hour periodicity producing

a net displacement of water toward the north-northwest. For 84 days this pattern persisted, the rotational movement at times disintegrating and reappearing, until the upper instrument stopped functioning. During the next 25 days the lower meter showed a gradual and systematic change in current direction, the daily displacement slowly veering clockwise until the net transport had become southwesterly by the time the buoy was picked up.

While it is recognized that there are in the overall system a number of factors that could and do introduce inaccuracies, the number of individual measurements involved (13,955 in all), the consistent, periodic current patterns which emerge and the gradual and progressive nature of change in these patterns cannot be considered anything but real. Additional validation is found in the consistent agreement between the records of the two instruments.

These data at present are the only direct, long-term current measurements ever made in this region, a fact that makes their interpretation difficult. There is no apparent relationship between the current record and the local winds as seen on 5-day mean sea-level pressure maps, nor can the currents be related to the phases of the moon nor to its declination.

The 24-hour periodicity does not agree with the inertial period of 25 hours, 28 minutes at this latitude. Rather it suggests solar influence, perhaps through radiation, perhaps through gravitation, perhaps through a combination of both. It may be significant that the major changes in the currents occurred around the time of the winter solstice and that the currents at 100 meters reversed direction as the sun began moving northward.

The data obtained in this experiment indicate once again the need for long-term, synoptic, direct measurements of the circulation in the open ocean if we expect to develop a realistic picture of this environment. Recent improvements in instrumentation and mooring techniques bring closer the day when such broad observational programs can be carried out routinely.

EVAPORATION

Dana Densmore

Throughout the Spring of 1963 we were preoccupied with preparations for the Indian Ocean Cruise 8 of ATLANTIS II, ordering, storing and keeping track of a great variety of gear. My earlier interest in evaporation fitted well with this activity, and for two months I maintained an "Hydraulic Organ" of plastic tubes in a housing on the roof of the laboratory building, measuring evaporation in various surface-area/depth ratios.

From early July through December I headed up the 4 to 8 watch aboard ATLANTIS II, as well as titrating the better part of some 6500 salinities. On each station an evaporating pan was used, extending previous Atlantic and Mediterranean data through the Red Sea and Indian Ocean. The evaporation rate is measured by the increase in salinity of the sample, by a formula modified from Wüst* and agreed to by Charnock. There has been, of course, no opportunity to work up or evaluate these data.

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*p.221, Physical Oceanography, Vol.I, Defant.

MEDITERRANEAN WATER IN THE ATLANTIC OCEAN

Frederick C. Fuglister

Various methods of using the temperature and salinity characteristics of the water masses to show the spreading of Mediterranean water in the Atlantic were compared.

According to Dr. Wüst this water can be traced over virtually the entire North and South Atlantic and the percentage of Mediterranean water present at any point can be determined from a curve for the Temperature/Salinity relationship in the core layer of this upper North Atlantic Deep Water. Dr. C. O'D. Iselin, using the Helland-Hansen anomaly method, shows that the water extends over a much smaller area, confined to the North Atlantic, north of 20°N. Dr. Albert Defant believes that this difference can be explained by differences in the definition of "Mediterranean Water" but he insists that "traces" of Mediterranean water can be followed far into the South Atlantic (Defant 1961).

It is certainly important to define the Mediterranean water carefully but the extent to which this water spreads is determined actually by the end point, or end points, chosen to represent zero Mediterranean Water. Presumably, in the "core" method, the end point occurs where the core or tongue ceases to exist. The question here is: to what extent does the presence of a core, say a layer of maximum salinity, depend on the presence of another core or minimum layer? Would the "traces" of Mediterranean Water at 2,000 metars in the South Atlantic be recognizable if the core of relatively fresh water, the Subantarctic Intermediate Water, were not present?

The method of Helland-Hansen depends on the choice of a "standard T/S curve" to represent zero Mediterranean Water; the anomaly is the variation of salinity at constant temperature.

An anomaly of salinity at constant sigma-t would seem to be more logical. It would show a greater influence of Mediterranean Water in the Atlantic but brings up the problem that there is no water in the Atlantic as dense as the water flowing from the Mediterranean.

Questions of this nature are being investigated because it appears that the influence of the Mediterranean outflow on the thermohaline structure of the Atlantic is frequently somewhat exaggerated. The North Atlantic would probably be the most saline of the world's oceans even if it were cut off from this source.

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EQUATORIAL CURRENT SYSTEM

William G. Metcalf and Marvel C. Stalcup

From mid-January to the end of April, equatorial current investigations were being carried out aboard CRAWFORD and CHAIN as a part of EQUALANT I, an international cooperative study of the equatorial region coordinated by the U.S. Bureau of Commercial Fisheries. CRAWFORD occupied 170 hydrographic stations in six north-south sections across the Equator mostly in a rectangle between 10°N and 10°S, and between 25° and 40°W. The track chart and the types of observations made are shown in Figure 1. Shallow profiles of temperature and salinity from the 25°W section are shown in Figure 2.

In all but one crossing, the Equatorial Undercurrent was observed to be running strongly to the east. At 40°W there was less evidence of a strong flow, and it is felt that the Undercurrent may receive most of its strength somewhat to the east of this line. At 35°W and south of the Equator, the wire angles on station indicated a very strong sub-surface flow to the north suggesting that this area may be important in the supply of the Undercurrent.

On three cross-sections (25°, 30° and 35°W) the water was sampled all the way to the bottom. At 27°30' and 32°30'W only the upper 1400 meters were sampled, and at 40°W only the upper 350 meters were sampled. The three deep sections all crossed the mid-Atlantic Ridge and penetrated the deep basins on both sides.

At the Equator on several crossings, buoys towed by parachute drogues in the Undercurrent showed sub-surface flow to the east of about a knot and a half.

One of the highlights of the cruise of CRAWFORD was the performance of the <u>in situ</u> salinometer designed by K.E.Schleicher and A.L.Bradshaw. Although various mechanical and electronic ailments of this instrument interfered with the program, two cross sections (25° and 30°W) were made with it, and the delineation of the sharp salinity maximum was far superior to anything that has been obtained in the past by any other method. This salinity maximum is apparently an extremely important feature of the Undercurrent, and invaluable data were obtained.

As part of the EQUALANT I cooperative program, CRAWFORD hydrographic station data were sent to the National Oceanographic Data Center in Washington, which is issuing the tabulated data plus charts of the horizontal and vertical distribution of properties in atlas form.

In addition to the CRAWFORD's hydrographic station work, the other chief material concerning the Undercurrent was obtained by CHAIN using Richardson current meters. These meters were set out in sections of five buoys, each supporting four current meters. After a week of continuous recording, the assemblies were moved to another location. One series of buoys with meters recording for one minute in each twenty minutes were left in place for two months.

Although a number of the film records from the current meters were rendered unreadable due to accidental radiation, some 50 useable records were obtained and are being analyzed. Early

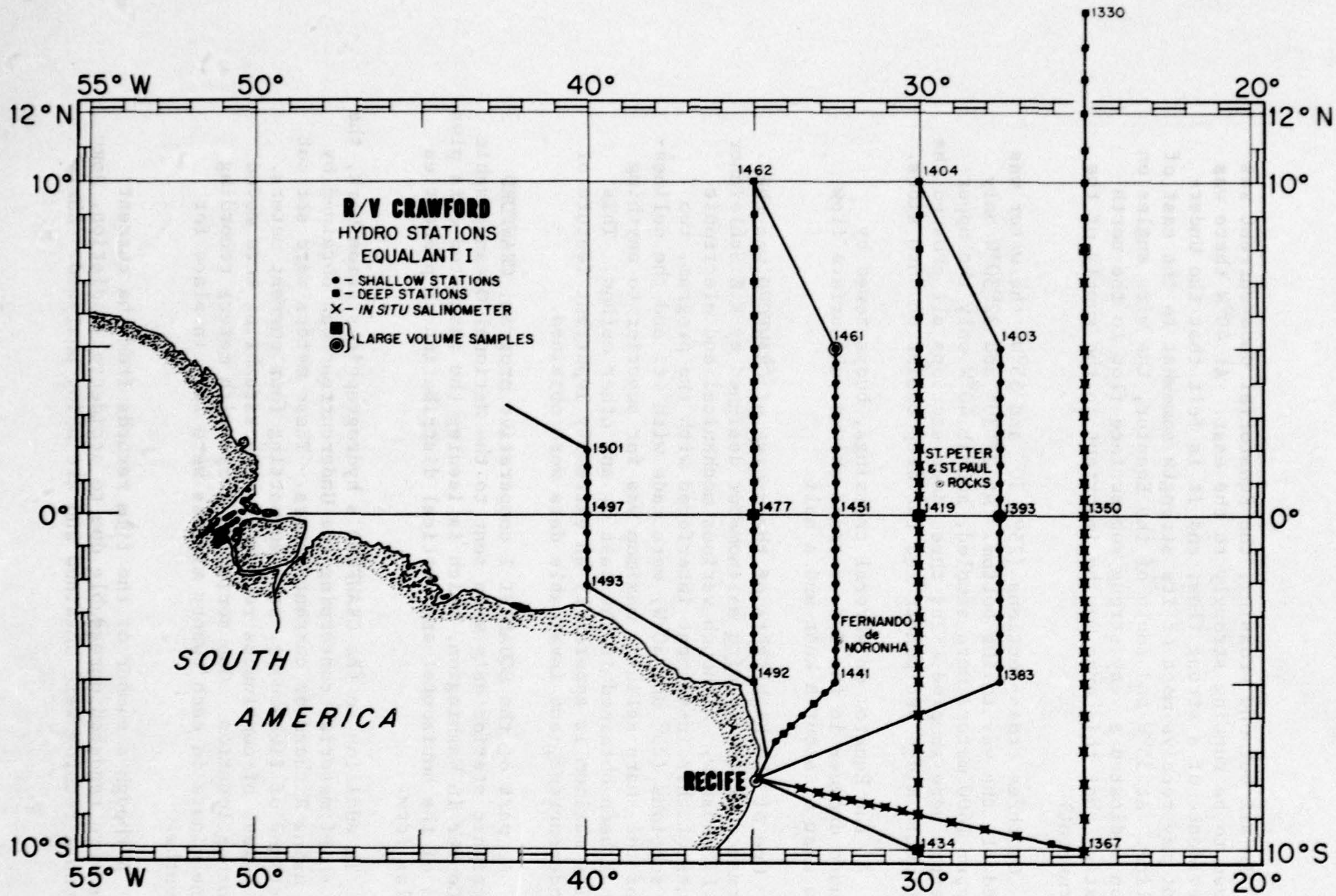

FIGURE 1. R/V CRAWFORD HYDRO STATIONS EQUALANT I.

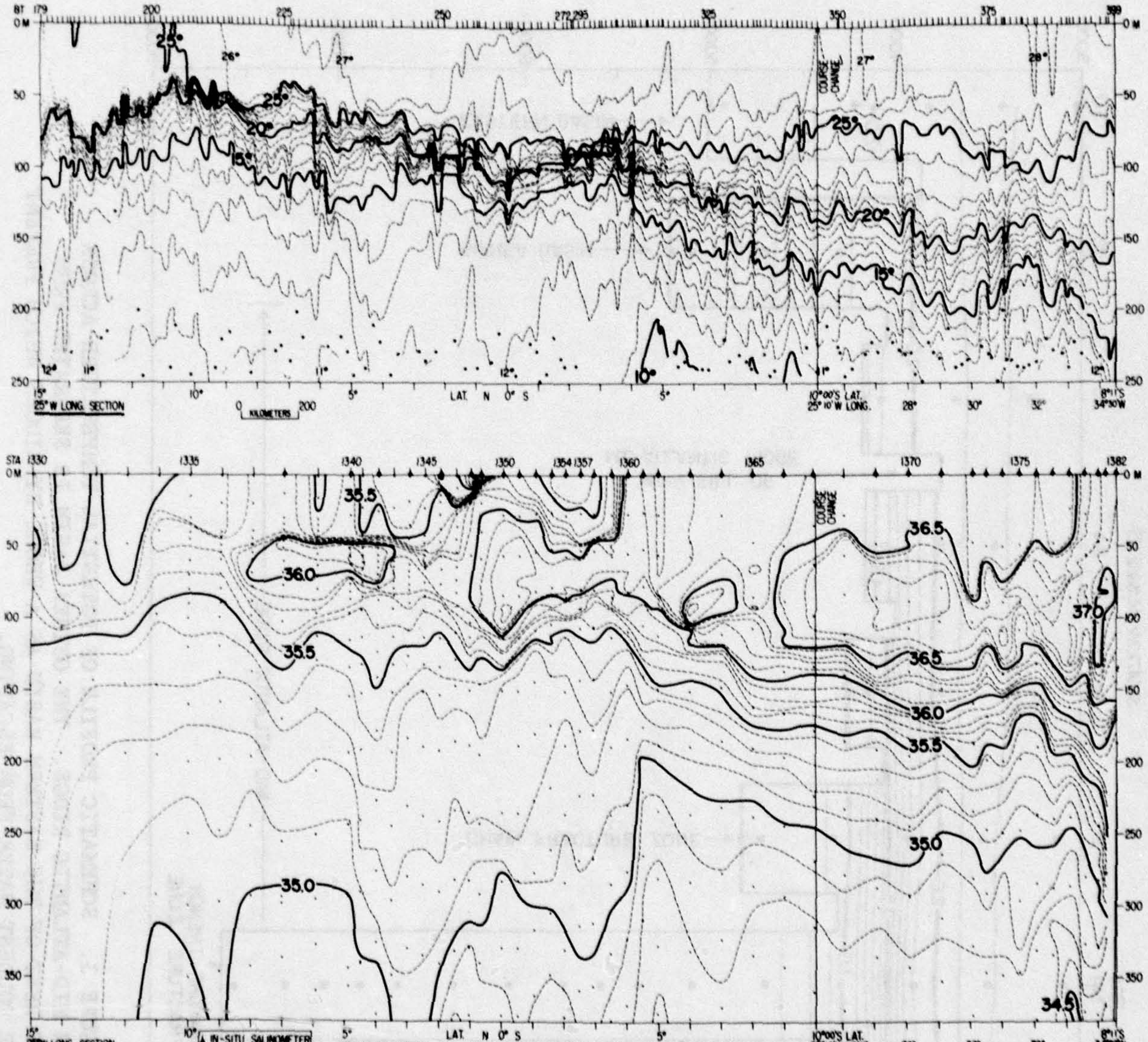

FIGURE 2. TEMPERATURE AND SALINITY PROFILES, EQUALANT I, R/V CRAWFORD

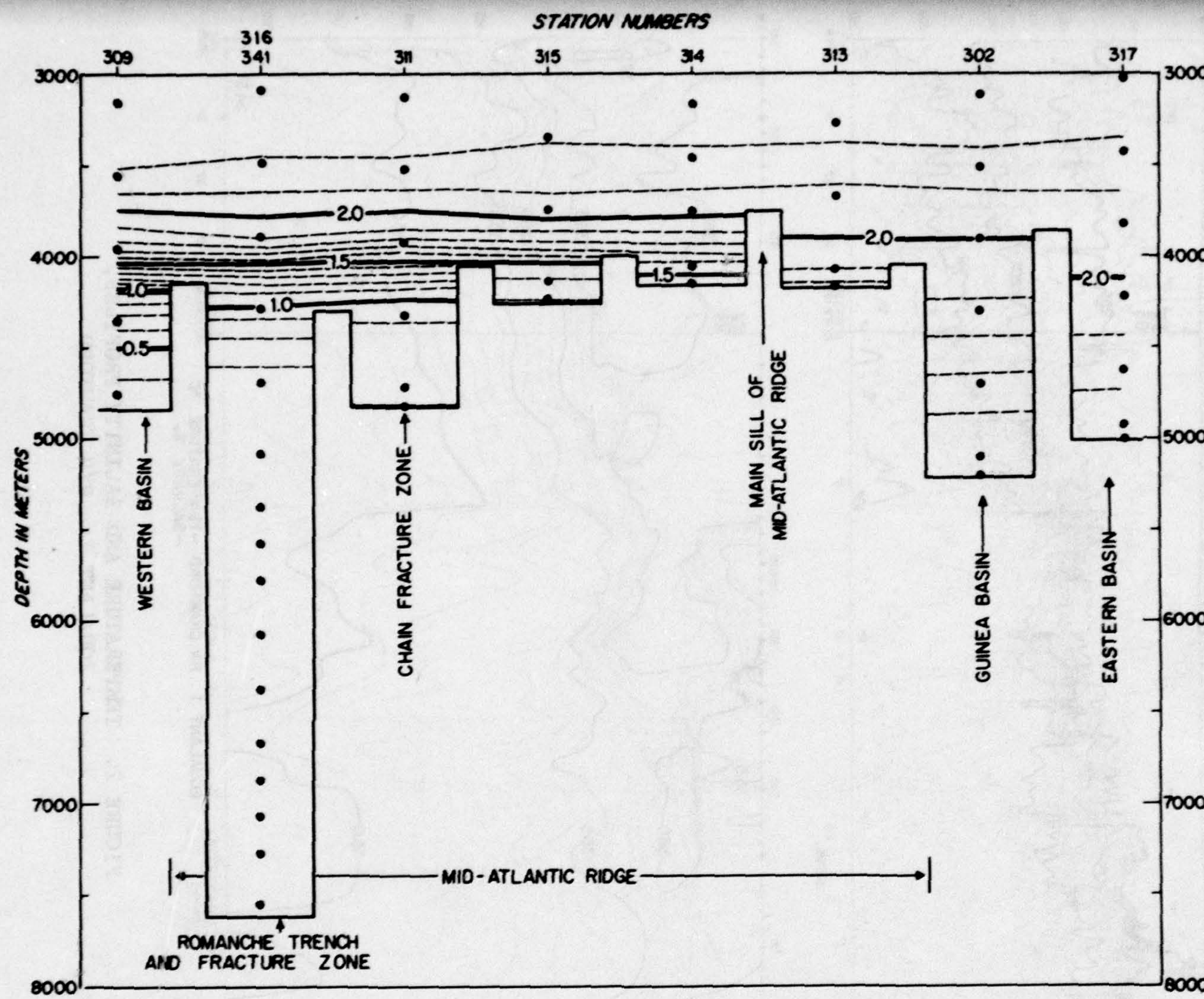

FIGURE 3. SCHEMATIC PROFILE OF POTENTIAL TEMPERATURE ACROSS THE MID-ATLANTIC RIDGE. THE GUINEA BASIN IS SEPARATED FROM THE REST OF THE EASTERN BASIN AS A WHOLE BY RIDGES WHICH PREVENT THE COLDEST WATER FROM ESCAPING.

spot checking of these records showed an interesting and fairly coherent picture of the current system. Further study has disclosed some unexpected idiosyncrasies in the behavior of the current meters, and further work is underway in an effort to recover as much data as possible. It seems safe to assume that a very large volume of good information about the Undercurrent will be obtained.

In addition to the above, work has continued on the equatorial data obtained on CHAIN Cruise 17 in 1961. In collaboration with Dr. Bruce Heezen of the Lamont Geological Observatory, a new estimate of the sill depth of the mid-Atlantic Ridge in the Romanche Trench region has been made. Previous estimates had ranged from 4000 to 4800 meters. A combination of bathymetric and hydrographic station data from cruises by CRAWFORD, VEMA and CHAIN indicates an effective controlling depth of 3750 meters. A report of this by Metcalf, Heezen and Stalcup has been accepted by Deep Sea Research for publication early in 1964.

Temperature observations from a series of stations taken to the bottom in the complex topography of the mid-Atlantic Ridge show a sequence of changes in the deep water as one passes from the cold Western Basin deep water into the somewhat warmer Eastern Basin deep water. A schematic illustration of this is shown in Figure 3. The Guinea Basin at the eastern end of the overflow path receives the coldest deep waters which crosses the Ridge. This Basin appears to be separated from the rest of the Eastern Basin by ridges which isolate the deep water. As a result, as is shown in the figure, the Guinea Basin bottom water is about 0.2°C colder than that of the rest of the Eastern Basin.

INDIAN OCEAN AND MEDITERRANEAN SEA

Arthur R. Miller

The first half of the year involved preparations for the ATLANTIS II participation in the International Indian Ocean Expedition. These consisted of ordering and acquiring scientific equipment for the new ship, testing and calibrating equipment, recruitment and organizing the scientific team, and setting up procedures to follow during the course of the expedition.

In the meantime the Mediterranean data from three cruises were not lying idle. Prof. Tchernia from Paris visited Woods Hole to work on some of these data and a joint contribution is in preparation for publication. Mr. Henry Charnock of the N.I.O. also

visited the Institution and is presently concerned with evaporation determinations over the Mediterranean. A volumetric salinity-temperature analysis is being conducted on the Mediterranean results with the initial determination of the volumes by one-degree squares already completed.

On July 5 the ATLANTIS II put to sea for her first long voyage to return 5½ months later on December 20 with about 30,000 miles to add to her log. Briefly, some of her accomplishments during this voyage were: (1) making possibly the deepest hydrographic station in the Mediterranean Sea - depth of the bottom bottle, 5098 meters; (2) finding a hot salt-water puddle (25^{o}, 43 $^{o}/oo$) in one of the Red Sea deeps; (3) charting and delineating the width and depth of the Somali Current; (4) making a complete oceanographic survey of the Arabian Sea during the height of the Southwest Monsoon which, coupled with the work of Royal Research Vessel DISCOVERY off the coast of Oman, should give the first comprehensive view of that sea during that season; and (5) obtaining detailed oceanographic information about the Reunion Basin and the waters from Madagascar to the Chagos Archipelago. It should be noted that new techniques were developed during this cruise among which were an electronically-rigged Nansen bottle to shut off a pinger sound source to indicate the completion of a hydrographic cast, use of a new navigation system, programming a general-purpose computer to determine results of observations while at sea, and determinations of various parameters concerned with the phenomenon of air-sea exchange by rain water analyses, continuous dew point recordings, total sky cover photography and net radiation measurements.

RADIATION

Robert Munns

The early part of the year was spent in working on Mediterranean data, particularly on the solar and net radiation components of the heat budget, and making preparations for similar work in the Indian Ocean.

The THRESHER search occupied a month of my time. This operation added very considerably to the knowledge and skill in precise ocean navigation and echo sounding for small-target location.

I was in charge of a two-week advanced-student cruise on the ATLANTIS. In addition to demonstrating the use of oceanographic

instrumentation contributions were made to the knowledge of the Gulf Stream.

The remaining half of the year was devoted to the Indian Ocean. Solar and net radiation measurements were made continually on ATLANTIS II for four months.

The British DISCOVERY was doing similar measurements. With the data from two ships and that planned for future Indian Ocean voyages a good understanding of radiative effects upon Indian Ocean characteristics should exceed that known for other oceans. These measurements have not been done before on a large ocean area and time scale.

RADIO DROGUES

Charles E. Parker

The experience gained in 1962 with radio drogues has shown that the tracking procedures used were not satisfactory in respect to the frequency-of-position reports.

The time interval between fixes was severely limited by the capabilities of the R4D aircraft through normal maintenance procedures compounded by occasional unsatisfactory flying conditions and personnel endurance. Because of these limitations lapses of up to three weeks had to be endured, and as the experiment showed (WHOI Ref. 63-13) much valuable information was lost. Some uncertainty developed as to the behavior of the drogues between fixes although gross current features could be seen for the four-month period.

In an attempt to overcome these deficiencies a new approach to buoy location has been developed using the existing Consolan stations maintained by the U.S.Government at Nantucket and Miami. A dual-frequency Consolan receiver and switching complex has been designed, constructed and successfully tested on the existing buoys (WHOI Ref. 63-12) under field conditions (CRAWFORD 95 and R5DQ flights 56 to 61).

Briefly, the signals received from the Nantucket and Miami Consolan stations are monitored in the buoy and directly retransmitted by the standard buoy transmitter for about one and one-half minutes each. At the end of the listening period the Consolan receivers and the transmitter are automatically shut down and the standard buoy receiver is put back on stand-by.

In practice any buoy can be called selectively for its position about twice during a 24-hour period from our Waquoit radio station. The incoming retransmitted Consolan signals are then put on magnetic tape for a permanent signal record and then transferred to a Sanborn recorder for plotting.

The effective range of this system is approximately 1000 miles from each station and a maximum of about 1200 miles. The area covered extends over about one million square miles of the Western Sargasso Sea. Twelve radio drogues have been prepared to be set out early in 1964 to track current flows at 1000 to 2000 m in an area west of Bermuda to the Gulf Stream. Life expectancy of each unit is about six months.

SALINOMETERS

Karl Schleicher

The _in-situ_ salinometer was used on board the CRAWFORD on the EQUALANT cruise during the first part of 1963. The instrument was used primarily to determine accurately the depth of the salinity maximum associated with the Equatorial undercurrent east of Brazil. For this purpose the depth-measuring section of the salinometer was altered so that the maximum depth of lowering was restricted to 375 meters, which increased considerably the accuracy in depth measurement over that possible with the original depth probe (which is capable of measuring depths down to 6500 meters).

For the first part of the cruise the salinometer operated satisfactorily and extremely useful data resulted from its use. Trouble was encountered at the start of the second half, however, and the instrument failed to function and could not be used for the rest of the cruise.

Since the _in-situ_ salinometer was completed in 1961 it has been used on six cruises with varying success. Though it has been extremely useful in showing details which could not have been seen by the standard hydrographical technique, its overall operation has not been entirely satisfactory. After the latest failure on its last trip serious consideration was given to the idea of changing it from a salinity-temperature-depth instrument to a conductivity-temperature-depth one. Briefly, this would have the advantage of simplifying somewhat the underwater section and , hopefully, make it more stable. The change should also make it possible to improve its accuracy and make it more versatile. One disadvantage of the

change will be a more complicated (and costly) shipboard unit. The decision was made to effect this change and work has been going on towards this end. This is not a simple conversion to make taking into account the system as a whole but it is felt that, if successful, it will result in a better overall instrument.

Steps were also taken in 1963 to redesign and rebuild the bridge and electronics section of the three existing shipboard salinometers. The purpose of this program is to increase the stability of the instruments and decrease the maintenance time which of late has been getting larger because of the effects on the bridge section due to salt-water contamination of the oil bath in which the bridge is immersed. The bridges will be converted to transformer bridges and everything will be removed from the bath except the cells, some switches and a few variable resistors. The electronics section will be transistorized.

TEMPERATURE VARIATIONS IN THE NORTH ATLANTIC

Elizabeth H. Schroeder

"North Atlantic Temperatures at a Depth of 200 Meters" was published in March, 1963, by the American Geographical Society as Folio 2 of the Serial Atlas of the Marine Environment. It includes nine colored charts which show the average temperature, range of observed temperature, deviations from the mean, and seasonal distribution of data. An appendix lists in tabular form the data used in compiling the charts.

An animated movie of average surface temperatures, covering an area from 20°N to 45°N and 65°W to 82°W has been completed. It is based on the monthly average surface temperature of each one-degree quadrangle in the area involved. A seasonal curve was drawn for each degree and monthly and half-monthly charts were constructed from the curves. The charts were used as a basis for the drawing of the 384 charts needed to complete the animation. A paper presenting these basic charts is now in preparation.

Because of the trend toward having all published work in Centigrade degrees, a study of average temperatures from the surface to 300 meters is being redrawn. The temperatures are summarized in a series of monthly profiles along eight meridians in the North Atlantic. To date, 56 of the 96 profiles have been redone.

INTERNAL WAVES

Arthur D. Voorhis

The extent to which internal waves are excited in the ocean and the forces which create them are problems which are of great interest to the oceanographer. To shed some light on these problems we have been investigating the spatial spectra of internal waves and their directional characteristics. Three series of measurements have been examined: one carried out east of Madeira in 1961, one at the Equator during EQUALANT I in 1963, and the last north of Bermuda also in 1963. In each case the measurements consisted of towing a temperature-sensitive element from a ship on a number of different courses at a depth of about 80 meters in the near-surface thermocline and recording the temperature variations due to internal waves. These records were digitized and spatial spectra of the waves (that is, the extent to which they were excited as a function of their wave length) computed using the G.E. computer. By comparing the spectra observed in different directions some idea of the horizontal directionality of the waves can be determined.

So far we have obtained spectra for wave lengths from 100 meters to 10,000 meters and they all show that the greatest internal wave amplitudes occur at the longest wave lengths. In the one case we have examined, we found that the internal waves with the smaller wave lengths appeared to be propagating down wind.

<u>THERMAL FRONTS</u>: A paper is in preparation which describes and discusses a number of thermal fronts which have been observed southeast of Bermuda between latitudes 25°N and 30°N during the last ten years. These fronts appear to extend from the sea surface to at least the bottom of the wind-mixed surface layer and are oriented in a general east-west direction. Across the fronts the water temperature changes by as much as 2°C in a distance of approximately 10 kilometers. Surface currents occur along the fronts which are in such a direction that the warm water lies to the right when looking down stream. Further work is planned to determine the extent of the fronts and whether they represent boundaries between different surface-water types.

VOLUME TRANSPORT OF THE FLORIDA CURRENT

Bruce Warren

Downstream from the Straits of Florida, the Florida Current increases several-fold in volume transport; the vertical shear of this increment, however, is compatible only in part with geostrophic inflow from the Sargasso Sea. Although insufficient current observations preclude direct estimates of transport, nevertheless, the vertical shear of geostrophic velocity is specified by horizontal density gradients, which therefore impose stringent limits on possible distributions of transport. Since, moreover, flow is expected to be approximately along σ_t -surfaces - except near the sea surface - an inquiry into the sources of the transport increment is being undertaken by computing under various assumptions the transports across several oceanographic sections in the Florida Current and Sargasso Sea between selected σ_t -surfaces.

As a preliminary result it appears that the downstream pressure gradient on the inshore side of the Current between the Straits of Florida and Cape Hatteras is about twice as great as that on the offshore side, and thus suggests a significant inflow to the Current from the slope water. This possibility is consistent with the large westward motions observed in the slope water by Volkmann (1962), and with the characteristics of deep water in the Gulf Stream, which seems to flow in the same direction as the surface current (Fuglister, 1963); in the temperature range where deep slope water is easily distinguishable from Sargasso Sea water (about 3.5 - 4.5°C), the water in the density gradients associated with the Stream has salinities much closer to those of slope water than of Sargasso Sea water.

In connection with this study, I participated in a cruise organized by J. R. Barrett, the object of which was to measure deep currents off the Cape Fear Arch. The motions observed were slight, but much of the program was frustrated by a hurricane and other storms.

A paper was published in Tellus, (Warren 1963) in which the large-scale meanders of the Gulf Stream, previously thought associated with a hydrodynamical instability, were related to the sloping topography of the Continental Rise. I have also prepared articles for a forthcoming Encyclopedia of Earth Sciences on the following subjects: physical oceanography, ocean currents, Gulf Stream, geostrophic motion, and Coriolis force.

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CURRENT MEASUREMENTS FROM MOORED INSTRUMENTS

Ferris Webster

Work on the eddy transfer processes in the Gulf Stream system evolved into an investigation of more reliable techniques for direct measurement of ocean currents. Analysis of data collected from current meters was closely connected to the work on instrument development and mooring design being carried out in the Applied Oceanography department. It is difficult to separate the work between two departments, since the design of instrument and mooring system, and the interpretation of the data are closely interrelated. The most fruitful advances came about when the collection system was modified on the basis of the data previously collected and when the data were examined with the physical behaviour of the instrument in mind.

A summary of some preliminary analyses of data collected before the summer of 1962 was published in Deep-Sea Research. These early results, which indicate that tidal and inertial motions are of importance in the open ocean, leave a great deal to be desired as far as accuracy of measurement and understanding of the mooring system behaviour. As a consequence, subsequent research has concentrated on two problems: (1) The diagnosis of instrument performance from an examination of the data collected, and (2) the development of a system for the rapid readout and processing of the large amounts of information which can be collected by such devices. A large measure of satisfactory progress in both of these tasks is necessary before any large-scale program of ocean current measurements can be undertaken.

A feature of the records collected to date has been the presence of persistent high-frequency (5 to 20 seconds period) fluctuations in the velocities. It has not yet been determined whether these fluctuations are the result of actual oceanic

fluctuations or are a result of instrument response. On the other end of the time scale, tidal period effects have been observed at nearly all locations and depths where current meters have been moored.

By the end of 1963, the processing of collected data was proceeding satisfactorily, using a high-speed digital computer. One setting of a single instrument yields nearly 200,000 current measurements recorded on a single reel of photographic film. The film is read by a digital computer system, and encoded onto magnetic tape for further processing. Several techniques for rapid graphical presentation, both of these original observations and of averaged quantities computed from them,have been developed. These presentations are being studied with the aim of constructing a model of the water current behaviour on which a time-series analysis system can be based.

WATER MASSES AND CIRCULATION

L. Valentine Worthington

A paper entitled "Anomalous conditions in the slope water area in 1959" has been accepted by the Journal of the Fisheries Research Board of Canada. It appears that in the spring of 1959 a large mass of cold water flowed from the Labrador Sea around the Tail of the Grand Banks and to a great extent replaced the slope water which is normally found between the Gulf Stream and the continental shelf east and south of the United States and south of Canada. This cold mass of water was first noticed in a section made on CRAWFORD in June 1959 along the meridian 57°30'W. Examination of bathythermograms for 1959 indicated that this cold water was not confined to the CRAWFORD section but was found to be wide-spread in the slope water area. The summer of 1959 was characterized by a very high incidence of fog at coastal stations in the northeastern United States and in southern Canada.

The cause of this influx of cold water is thought to have been related to an event in the North Atlantic weather pattern in the winter of 1958-1959. Starting in December 1958 and persisting through January and part of February 1959 the Icelandic low weakened and shifted from its normal position resulting in prolonged and intense easterly gales south of Greenland.

The amount of water movement involved (estimated at 50 million m^3/sec) seems very large. It is roughly one-half the

volume transport of the Gulf Stream. If such large water movements can indeed be initiated by anomalous weather patterns which persist for only about two months we should know more about them. The paper is a preliminary suggestion that such events are at least possible.

An examination of deep temperature measurements made in the Caribbean in the years 1933, 1937 and in 1958, during the International Geophysical Year, raised the question of whether or not the deepest waters of the Caribbean were becoming warmer. The four principal basins, the Yucatan, Cayman, Colombian and Venezuelan have been examined to the extent that the rather scarce deep temperature measurements persist. Roughly speaking, the deepest water in the Cayman Basin appeared to have been 0.03°C warmer in 1958 than in the earlier surveys, the Yucatan 0.02°C warmer, the Colombian 0.01°C warmer and the Venezuelan essentially unchanged. The 1958 data have been put through a computer program to determine stability (10^8E.). All the basins except the Venezuelan appear to have a layer (varying in thickness) of neutrally-stable water from the bottom up. This suggests that the warming may have been caused by heat flow through the bottom which would be consistent with neutral stability.

An opportunity to check on this matter was presented when CRAWFORD concluded a project in West Indian waters in early September. Two detailed oceanographic sections were made, one from the Atlantic into the Venezuelan and Colombian basins through the Anegada and Virgin Passages and the other from the Cayman basin out into the Atlantic through the Windward Passage.

The results confirmed the evidence gained during the I.G.Y.: the temperature of the deep water in the Venezuelan basin is unchanged while that of the Cayman deep water has apparently increased by 0.03°C or more. The question of whether or not the deep water of the Cayman basin is neutrally stable or not is most critical. It has been commonly supposed, in the case of deep basins into which water has flowed over a shallow sill, that the potential temperature decreases very slightly with increasing depth. This is perhaps due to the use of Helland-Hansen's (1912) tables for potential temperature. More recent works by Fofonoff (1960) and Crease (1962) suggest that the adiabatic gradient may be weaker than Helland-Hansen supposed and that in consequence many other basins throughout the world may in fact be neutrally stable.

The temperature and salinity data from the CRAWFORD cruise

are now ready for the computer and potential temperature will be determined according to Fofonoff's and Crease's polynomials and compared with Helland-Hansen's. Furthermore, stability (10^8E.) will also be determined according to the methods of Fofonoff and Crease.

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THEORETICAL OCEANOGRAPHY and METEOROLOGY

DEPARTMENT OF

THEORETICAL OCEANOGRAPHY AND METEOROLOGY

Columbus O'D. Iselin, Department Chairman

AIR-SEA INTERACTION

Duncan C. Blanchard and A. Theodore Spencer

We did not engage in any field trips in 1963; all of our work was performed in the laboratory. Some new research was initiated, some developmental work was carried out, and much time was spent in the writing of papers.

A considerable amount of time was spent in an attempt to develop an airborne spray system that could atomize sea water at a rapid flow rate and into small drops. It was shown that the method was not feasible economically; future plans for salt seeding in the atmosphere will utilize pulverized dry salt.

Some studies were carried out in the area of bubble photography, phase changes on airborne saline drops, flame photometry, and methods of data reduction. This resulted in two papers and both have been accepted for publication. One is on the flame photometric analysis of raindrops and the other concerns condensation nuclei and phase changes.

We have analyzed our data relating to space charge and potential gradient that were collected during our 1961-1962 field trips and have found evidence to support the hypothesis that a flux of positive charge is being carried from sea to air by drops from bursting bubbles. This material is being prepared for publication. The detailed study of this problem, which covers the flux of particulate matter as well as that of charge, appeared in Progress in Oceanography in November.

Another mechanism of particle and charge production by the sea which has been of interest is that which occurs when molten lava flows into the sea. The charge separation per unit mass of water is extremely high and cannot be explained by existing charge separation hypotheses. We suspect that this mechanism of charge separation may be akin to that of the jet drop from bursting bubbles. Further study is imperative; in the meantime these ideas have been expressed in a paper that has been submitted for publication.

A final phase of the work concerns the connection that must exist between dissolved organic material in the sea and particle and charge production at the surface. Our ideas on this subject are very tenuous at present but center around the fact that the surface free energy of a bubble must change as surface-active material is adsorbed to it as it rises through the water. The change in surface free energy is reflected by a change in the dynamics of the bubble collapse at the surface of the sea. Any change in the mechanism of bubble

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collapse will profoundly modify the electric charge separation and particle production. Some of our work of the past few years suggests strongly that the above sequence of events is taking place, and we intend to follow this up during the coming year.

AIR-SEA INTERACTION OF THE INDIAN OCEAN

Andrew F. Bunker

The first five months of 1963 were spent in building and installing equipment in the WHOI C-54Q aircraft BUNO 50874. The equipment consisted of a thermistor psychrograph, solar radiometers, cloud cameras, dropsondes, Doppler radar, search and weather radar, and turbulence and turbulent flux measurement recorders.

A six-week flight to the Indian Ocean area was made in June and July to study the southwest monsoon weather. Flights were made out of Bombay over the Arabian Sea to collect data to transmit to the International Meteorological Center at Colaba Observatory for study and distribution. This data included temperature, humidities, winds, clouds, and radiation. In addition, measurements were made of the turbulent fluctuations of the wind, temperature, and water vapor, so that fluxes of heat, water vapor and momentum through the atmosphere could be computed.

The remainder of the year was spent reducing the data and modifying equipment for the next flight scheduled for January 1964. Some preliminary analysis of the data has been made which showed the modification of the air mass as it flows over the Indian Ocean toward India. The lifting of the temperature inversion and the formation of cumulonimbus clouds are shown to be related to convergence of the wind field, but complete analysis of the data will be needed before the exact relationship is determined.

AIR-SEA INTERACTION

Eric B. Kraus

1) Heat Flux and Surface Stress

Studies under Contract SC 90784 are concerned with interaction between the air and sea. Stress under conditions of different wave fetch is to be studied with the help of systematic observations on both sides of a flat island across the tradewind stream. The effect of vertical stability - as represented by the diurnal change of air temperature - is also to be investigated. Preparatory work dealt with the theory of transfers across a wavy surface, with the selection of Aruba, N.A., as a working site which satisfies the requirement of exceptional wind steadiness and with a good deal of instrumental development.

2) New Equipment

A stable buoy has been constructed with funds from Contract SC 90784 to carry meteorological instruments without movement and without disturbance of the airflow in a relatively heavy sea. This development, as described in reports and a note in "Oceanus", has aroused the interest of several groups throughout the country and abroad.

A new type of wave sensor, which records digitally and has little power requirements was developed for the project by Messrs. Heinmiller and Armstrong at Woods Hole Oceanographic Institution. Some corollary studies were carried by a summer student, Mr. Morisetti. A new multiple, digital temperature recorder has been developed for the project by Geodyne Corporation.

3) Air-Sea Interaction over the Open Ocean

The analysis of the ensemble of weather ship data resulted in a study of the diurnal variations of precipitation over the open sea and its cause. This has been published in the November issue of the Journal of the Atmospheric Sciences. The work is being extended now to the systematic study of vertical heat flux and evaporation with their spatial and temporal variations, as far as this can be ascertained from all synoptic observations on all North Atlantic weather ships during the past fifteen years. Statistical processing is carried out at the National Data Center in Asheville, North Carolina. The work is financed under National Science Foundation Grant GP 317.

4) Sea Spray and Its Role in Momentum Transfer is investigated by Mr. Monahan under National Science Foundation Grant GP 317.

5) The Effect upon the General Circulation of the Distribution of Land and Sea over the globe is being studied by means of a numerical model. In order to study the effect statistically, it is planned to generate "100 years of weather" numerically. An equivalent to 25 years' weather data has been generated so far on the Institution's GE 225 computer. The work is carried out in cooperation with Prof. E. W. Lorenz, M.I.T. The computer program has been prepared by Mrs. Gillie, M.I.T.

CLOUD PHYSICS AND DYNAMICS

Joseph Levine

The period from January to June, 1963, was spent on writing my thesis, "The dynamics and mass exchange of positively-buoyant elements in cumulus clouds". The work of the thesis was the result of a combined theoretical, instrumental, and observational approach to the physics and dynamics of cumulus convection started in 1960. The thesis was returned for further work.

The month of July was spent on building up and installing instruments in the C-54Q in preparation for the August field trip to Barbados. The Barbados trip was a cooperative effort organized by Prof. Joanne Malkus for studying the interaction of the trade winds with the island and for relating cloud patterns observed from our aircraft to Tiros photographs.

My cloud liquid-water-content instruments functioned properly towards the end of the field trip, but the turbulent vertical-velocity equipment was only partially successful in its operations. A new component in the turbulence instrumentation, which operated successfully throughout the field trip, was an integrator for the vertical-accelerometer output. The turbulence system as constituted represents the first step in the development of an analogue combination of the components, which enter into the computation of turbulent vertical velocity in clouds.

The remainder of the year was spent on reduction of the Barbados and earlier field-trip data and recalibration of the cloud liquid-water-content instruments in a wind tunnel at Hanscom Field. In the new calibration, provision was made for maintaining constant voltage on the liquid-water instruments, and many more shadowgraph pictures of drops in the tunnel were taken than previously. Thus data for more accurate calibration of the instruments was obtained.

MARINE METEOROLOGY

F. Claude Ronne

During 1963 Marine Meteorology continued to use photography as one of its major tools for collecting and recording both phenomena and data. Hundreds of feet of ciné color films of cloud formations and hundreds of black and white photographs were used to supplement the extensive field programs undertaken by this group in the West Indies and the Indian Ocean.

The C-54Q aircraft which was first used this year offered a new opportunity for using photographs for recording purposes.

This aircraft is equipped with a data panel on which are displayed the indicating dials for time, compass direction and Doppler navigation (Fig. 1). A 35 mm automatic camera was installed to photograph this panel continuously during the operational hours of flight. An interval of 20 seconds between pictures was chosen as being sufficiently frequent to obtain all pertinent information, while not being so frequent as to burden the program with excessive and unnecessary amounts of exposed film.

Such photography is certainly devoid of all glamour, but the unfailing memory of the camera is decidedly advantageous for the accurate reduction and interpretation of all the data obtained by the investigation.

THEORETICAL OCEANOGRAPHY AND METEOROLOGY

Peter M. Saunders

A radar study was made of tropical marine showers from the island of Barbados in the E. Caribbean in August. A 10 cm radar operated jointly by McGill University and Florida State University was calibrated with balloon-borne spherical targets. Developing small showers were selected and the rate of change of radar reflectivity was measured within them (maximum values of between 4 and 8 db/min). This reflectivity increase is to be interpreted in terms of the growth of small rain drops; its magnitude is consistent with estimates of the rate of coalescence of drops under gravity. Thus in the clouds studied the role of drop electrification in enhancing the growth process is probably small.

Measurements were also made of the manner in which the peak reflectivity in shower clouds was related to the maximum height

SCIENTIFIC INSTRUMENT PANEL (PHOTO-PANEL) ON C54Q AIRCRAFT.

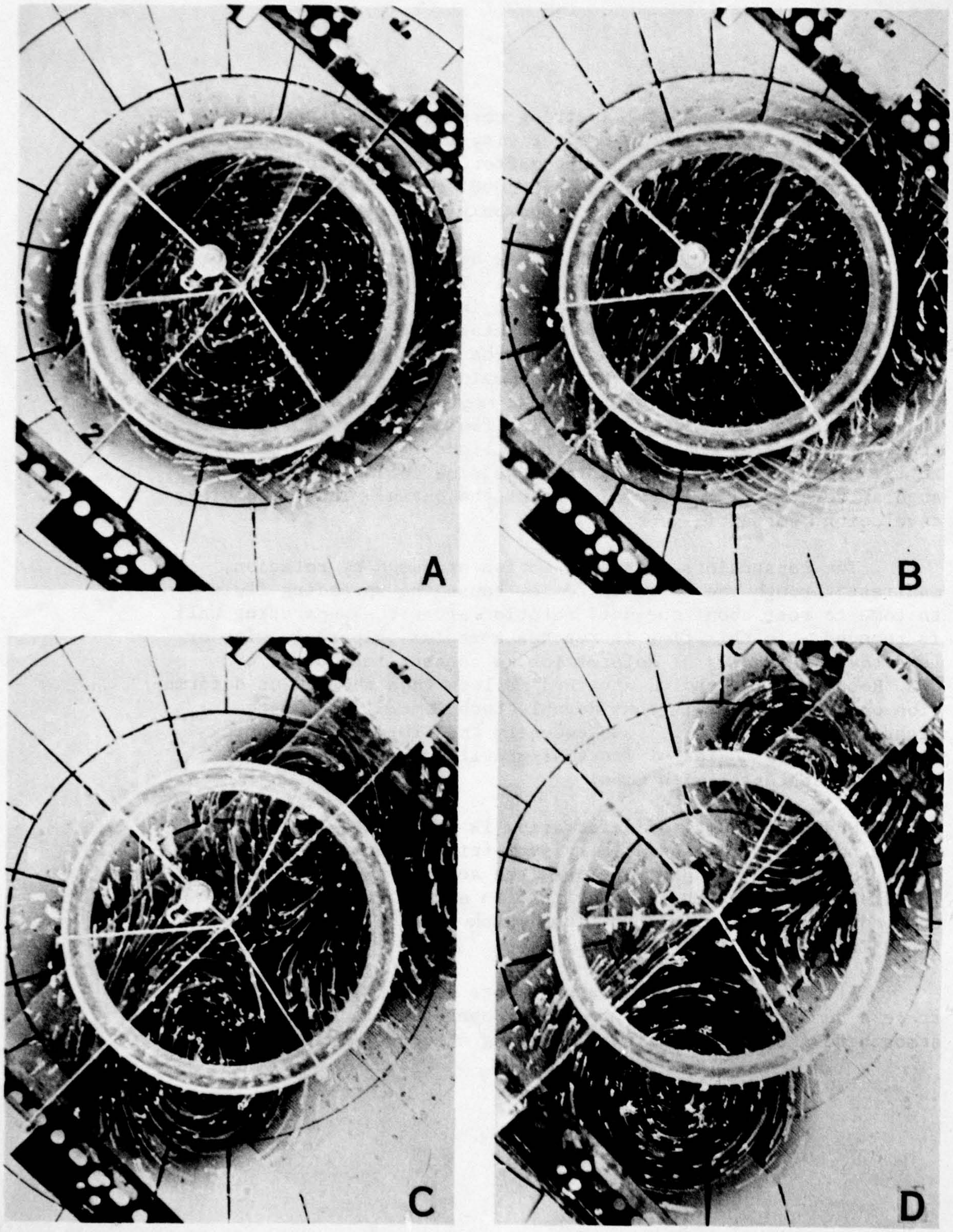
attained by their summits. A strong correlation was obtained showing a rapid increase in reflectivity in the height range 12 - 17,000' and a saturation thereafter. Thus the reflectivity (and hence rain intensity) from a 50,000' cloud is not substantially larger than that from a cloud only 1/3 of its size.

A preliminary investigation has been made of the characteristics of certain baroclinic vortices. They have been generated in the large (2.5 m) rotating basin by introducing a column of heavy fluid in the central region of otherwise uniform fluid. When a (cylindrical) wall separating the fluids is removed, the heavy fluid sinks under gravity and begins to spread over the bottom of the basin. Because angular momentum is conserved, the angular rotation of the spreading fluid becomes smaller than that of the basin. On the other hand light fluid which converges in the upper parts to replace the subsiding column acquires an angular rotation in excess of that of the basin. Thus a complex, developing, vortex is generated.

The constraints on radial motion produced by rotation, manifest through the Coriolis force, cause the spreading fluid to come to rest about one-half rotation after the separating wall is removed. In this time it reaches a radius comparable with or less than the radius of deformation, a concept introduced by C-G. Rossby. (The radius attained is less than the radius deformation only when there is considerable turbulent mixing of the light and heavy fluids.) Subsequently the fluid in the vortex is subject to a series of inertial-gravity oscillations whose amplitude decreases with time.

When the radius of deformation is small, the central vortex no longer remains axially symmetric but breaks up into a number of smaller stable vortices (see accompanying photographs). The instability, which is baroclinic in origin, occurs in these unsteady experiments in conditions which closely parallel those found in steady dishpan studies.

Although complex, the experiments described above illustrate a number of important processes operating in the oceans and atmosphere and pose certain interesting theoretical problems.



THE INSTABILITY OF A BAROCLINIC VORTEX

WHAT KEEPS THE SALT UP IN THE SUBTROPICAL THERMOCLINE?

Melvin E. Stern

This paper has been submitted for publication in Tellus.

This paper continues the discussion of the convective motions which occur when a reservoir of warm saline water lies above one of cold, fresh, and dense water. At highly supercritical thermohaline Rayleigh number the motion in the interior of the fluid may consist of vertical columns which are alternately (in the horizontal) rising and sinking through a stratified thermal field whose vertical gradient is constant. The amplitude of the sinusoidal velocity field satisfies the conservation laws in detail. A direct application of this result to the oceanic thermocline leads to a mixing rate for salt which is four - five orders of magnitude greater than the rate at which surface evaporation re-supplies the salt.

We then examine the stability of this equilibrium solution and find that the columns must buckle in an oscillatory mode at Reynolds numbers which are much less than unity. The energy source for this second transition is due to the horizontal variations in salinity associated with the undisturbed columns. It is suggested that at large values of the relevant non-dimensional parameter the stirring produced by the induced lateral motions becomes strong enough to entirely disrupt the basic salt column in a vertical distance which is much less than the thickness of the thermocline. If salt columns, such as are observed in the laboratory, exist in the ocean it can only be as a micro-convection which intermittently supplies energy to disturbances of larger dimensions.

WIND-GENERATED WAVES

Raymond G. Stevens

The past year has been devoted to refinements of the analytical procedures, instrument system and data-processing system employed in the investigation of wind-generated waves.

While some experimental design criteria have been established for a detailed investigation of the directional spectra of ocean waves there remains a pressing need to explore the statistical effects of sampling variability on the measured directional spectra.

Although the instrument system for wave and wind observations has been functioning satisfactorily it has found rather little employment. During the past summer it was intended to observe the growth and development of the directional spectrum during the sudden onset of the southwest sea breeze. The sea breeze, which has been a typical meteorological event during the early summer for the past several years, provides an ideal situation for observing the rate of growth of wind-generated waves and the development of directional characteristics. However, during the past summer the sea breeze was notably absent, and when it did occur it was characterized by a slowly-increasing wind from the southeast or east. Although the location of the observing tower is not suitable for observing waves generated by winds from those directions, a few moderately interesting situations were observed. However, there was rather little incentive to carry out extensive observations since the data reduction and analysis system is not operational.

Conversion of the data-reduction equipment for use with the GE 225 computer is essentially completed, and some portions of the data-analysis programming have been completed. It is expected that by early spring of 1964 an automated data-processing system will be operational which will require only four hours to calculate a directional spectrum beginning with the analogue tape-recorded data and ending with a graphic display of energy vs direction and frequency.

Another activity of this research has been to install a ship-borne wave recorder on board ATLANTIS II prior to her departure for the Indian Ocean cruise in July 1963. The apparatus consists of an NIO ship-borne wave recorder operated in conjunction with an analogue-to-digital converter, which punches on paper tape the observed wave height twice per second. The punched paper tape is then fed into a Control Data G-15, general-purpose computer, which is installed adjacent to the wave recorder, and the wave power spectrum is computed. Since the equipment does not require a highly-skilled operator, and since it requires little attention while recording or calculating it may be operated routinely whenever the ship is hove to at an ocean station for a period of ten minutes or more.

A total of 194 wave-spectrum observations were made in the North Atlantic Ocean, Mediterranean Sea, Red Sea and Indian Ocean during the first five months of the Indian Ocean Cruise, although the equipment finally failed due to a burned-out transformer before completing the last leg of the cruise through the South Atlantic Ocean.

It is anticipated that the power spectra together with weather maps and local wind observations, if made available as a data report, will be of considerable value to ocean-wave forecasters.

The wave recorder has been somewhat modified and reinstalled aboard ATLANTIS II, and will be operated during the winter and spring of 1964 in the North Atlantic Ocean. It is hoped that the observations made on this cruise will provide a measure of the modification of the wind-generated wave spectrum due to the influence of the Gulf Stream. Unfortunately, the digital computer has been removed from the ship so that correlation of visual observations with measured spectra cannot be made but much useful information can be derived from a post-analysis when the ship returns in May, 1964.

LABORATORY MODEL EXPERIMENTS

J. Stewart Turner

Work has continued this year on various theoretical and laboratory models of dynamical processes in the ocean and atmosphere. Most effort has been put into an experimental analogy of the tornado vortex, which is driven by convection and takes into account the effect of the surface below. A paper on this subject was presented at the U.G.G.I. meeting in Berkeley, and a preliminary account has been published jointly with D. K. Lilly of the U.S.Weather Bureau. More detailed measurements of the flow and the associated theoretical analysis are now being carried out.

Several theoretical ideas about the motion of buoyant "thermals" have been developed and written up. A kinematic model of the motion has given good agreement with previous observations, and it has been shown how the overall motion can be predicted from the nature of the exterior flow alone. Some progress has also been made towards a detailed description of the interior velocity and density distributions.

Experiments have been begun on a model of the upper mixed layer in the ocean. These promise to give an explanation of the sharp density interfaces, and the dependence of the density structure on the changing rate of heating during a yearly cycle.

During the summer twelve lectures were given on the subject of "Turbulent Processes near the Air-Sea Interface" as part of the course on Advanced Physical Oceanography. There was also an opportunity to attend some of the Geophysical Fluid Mechanics

course, and to give a seminar to that group. An invitation from the Meteorology Department at McGill University resulted in a visit there, during which three lectures were given to their Cloud Dynamics group.

WIND-DRIVEN OCEAN CIRCULATION

George Veronis

The majority of my time was spent on a theoretical model of wind-driven ocean circulation. The model is a study of the interaction of various physical processes in the ocean. Specifically, the vorticity equation contains non-linear terms, time dependence, friction, the curl of the wind-stress and the β-effect. The stream function is represented by a truncated Fourier series and the resulting equations for the Fourier amplitudes are solved. The results are that a) for a sufficiently weak wind-stress curl the final steady-state solution corresponds to that given by Stommel in 1948; b) for a sufficiently strong wind-stress curl the final steady-state solution takes a form similar to the pattern of the wind-stress curl; c) for intermediate values of the wind-stress curl (observed values fall in this range) the ocean settles into no steady state but oscillates and pulsates in a complicated but periodic fashion. Throughout the foregoing the wind-stress curl was taken to be a single anti-cyclonic gyre covering the entire basin.

A further result is that non-linear effects combine with the β-effect to give a statistically steady circulation when the ocean is driven by an oscillating (zero-average) wind-stress curl of small scale. The model is still under investigation.

Part of my remaining time was spent on an analysis of the approximations made in transforming the equations of motion from a sphere to the β-plane. It was shown that the domain of validity of the β-plane reaches to within a fraction of a degree of the equator for a baroclinic system.

The stability of a layer of fluid with a stable salt gradient and an unstable temperature gradient has been studied. The results indicate that the system becomes unstable to finite amplitude disturbances before it becomes unstable to infinitesimal disturbances. This (continuing) study may help in our understanding of some of the T-S properties of the ocean.

During the summer I directed the Geophysical Fluid Dynamics summer school. A report of this program is available.

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